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CONTENTS

EDITORIAL: EXTERNAL AFFAIRS		195
AN ENGINEERING APPROACH TO THE RATING OF AIRCRAFT FLUID FILTERS	*J. W. Noonan*	196
THE DEVELOPMENT OF THE STOL AIRPLANE	*A. F. MacDonald*	203
THE DESIGN AND TESTING OF AN AIR INTAKE FOR A SMALL SHAFT POWER GAS TURBINE	*Dr. J. H. T. Wade*	207
NEW PROBLEM AREAS IN AIRCRAFT PROPELLER DESIGN	*G. Rosen*	213
TECHNICAL FORUM		
A Two-Distribution Interpretation of Fatigue S-N Data	*S. R. Swanson*	221
Design of Ground Effect Vehicles	*Dr. W. R. Bertelsen*	223
The Evolution of Aircraft Maintenance	*R. J. McWilliams and I. J. Kessler*	225
Propulsion Systems for Space Travel	*D. C. Weiss and Dr. H. S. Ribner*	226
INTERNATIONAL CONFERENCES		227
C.A.I. LOG		230
Secretary's Letter, Branches, Coming Events, Appointment Notices, Members, Books		

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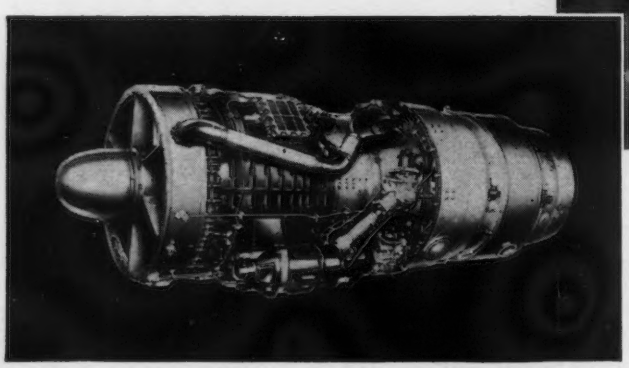

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HOW MANY "G"s?

The ever-increasing swiftness of modern planes brings many problems of maintenance—a major one being the question of airframe overhaul. An overhaul schedule based on the number of flying hours or on a calendar time limit is no longer adequate for airframes exposed to the torturous stresses of near supersonic speeds. The structural condition of two aircraft having flown an identical number of air-hours may be quite different. One may have been exposed to high G-loadings for short periods during apparently routine flights, while the other may not have been subjected to any such stresses. This G-loading factor is known to be an important one in the wear and fatigue of an airframe. Question: How to keep a cumulative record of the "G" forces acting on an aircraft during a series of flights?

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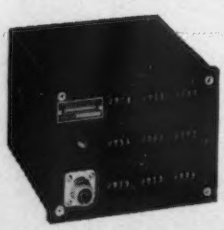

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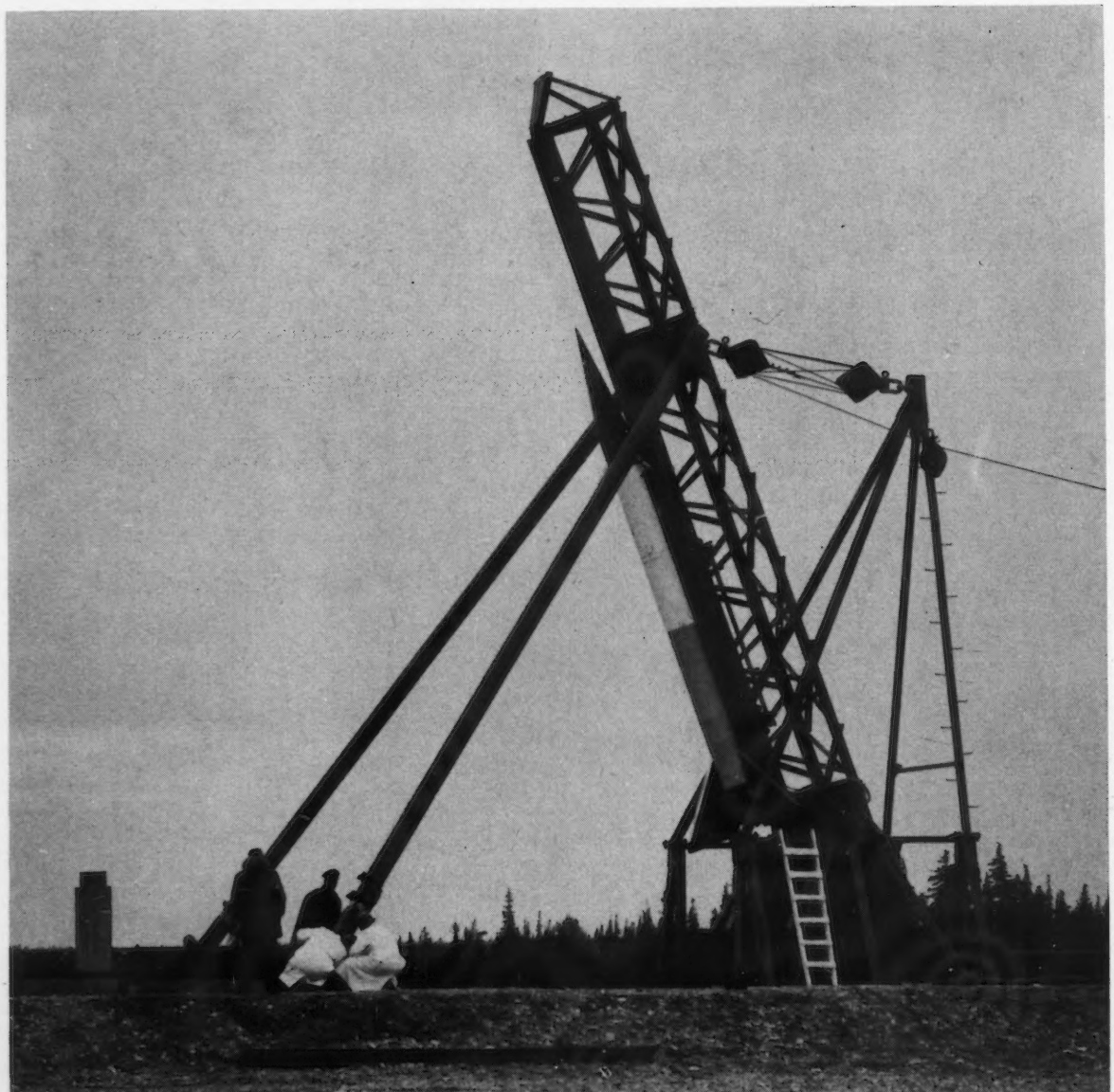

One of the 24 ft Black Brant propulsion test vehicles, developed by CARDE, which was successfully launched at Fort Churchill early last September.

EDITORIAL

EXTERNAL AFFAIRS

It is interesting to review the various international conferences dealing with the flight sciences, with which the Institute is now associated one way or another. Participation in such conferences is of considerable value. On the one hand it gives Canadian scientists and engineers an opportunity to obtain information on the work being done in other countries, perhaps in fields which are at present inactive in Canada. They can discuss this work at first hand – at the sessions, if they are quick enough, or, more often, at social gatherings afterwards – and, in total, the knowledge so gained cannot but enhance their understanding of their own work and of its place in the broad scheme of aeronautical progress. Moreover the personal contacts made and the sources of future reference established are sometimes invaluable. On the other hand participation implies contribution and Canadian contributions, though necessarily rather limited, are earning increasing recognition from the scientists and engineers of other countries.

The international conferences of immediate concern to members of the Institute are these:

International Congress in the Aeronautical Sciences

The Second of these Congresses is due to take place in Zurich, Switzerland, from the 12th to the 16th September. Its full programme appears on pages 227 to 229 and includes three Canadian papers – by Dr. Maiden of CARDE, Dean Mordell and Mr. Swithenbank of McGill, and Dr. Morgan and Mr. Buhr of the Department of Mines and Technical Surveys. At the First Congress at Madrid two years ago, Professor Etkin of the University of Toronto presented a paper, contributed jointly by himself, Dr. Neely and Dr. Ribner. This increase in Canadian participation, in these times, is gratifying.

Dr. Green and Dr. Patterson, both Past Presidents of the Institute, are members of the International Council of the Aeronautical Sciences, under whose auspices these Congresses are held. The CAI officially represents the interests of Canadian scientists and engineers in the administrative side of the business.

Anglo-American Conference

These Conferences between the Royal Aeronautical Society and the Institute of the Aeronautical Sciences have been going on, on alternate sides of the Atlantic, every two years since the war. Last October, in New York and Toronto, the CAI took part for the first time; Canadian papers were presented by Dr. Bull of CARDE and Mr. Hiscocks of De Havilland of Canada, and members of the CAI were admitted on the same footing as members of the originating societies. The RAeS has extended an invitation to the next Anglo-American Conference, to be held in England in 1961, and the Institute is looking forward again to this family gathering.

SAE International Congress and Exposition

The Society of Automative Engineers is arranging a very large congress in Detroit in January 1961 and has invited the CAI to take part. There is a notice about it on page 229. The Institute's contacts with the SAE have not been very many in the past but, of course, the work and reputation of this Society is known to everybody who has any experience in aeronautical engineering and the Institute is looking forward to getting to know them better as an organization.

Joint IAS/CAI Meeting

Joint meetings with the IAS have been held annually in Canada since the CAI was formed. They are so much a part of the Institute's programme that it requires an effort to recognize that they are indeed international. But, though they have all the friendly relationships of home affairs, they have all the merits and benefits of international meetings as well. The next will be held in Montreal in October.

International Astronautical Conference

The XIth International Astronautical Conference will be held in Stockholm, Sweden, from the 15th to the 20th August under the auspices of the International Astronautical Federation. The Institute is not a member of the IAF, as it is of the ICAS, and is not participating in this Conference. Nevertheless the IAF has kindly furnished full particulars and because the programme of scientific papers is of considerable interest an outline was published in the March issue of the Journal.

The chief difficulty associated with international conferences is that they usually involve travel to far away places. It is a real difficulty but it is one which is not unfamiliar to Canadians. Is it really too high a price to pay for the professional benefits and the prestige inherent in strong Canadian representation?

AN ENGINEERING APPROACH TO THE RATING OF AIRCRAFT FLUID FILTERS†

by J. W. Noonan*

National Research Council

INTRODUCTION

In large cities like New York and Chicago, the particle density in the atmosphere is of the order of one to three million particles per cubic foot. In a large industrial centre such as Pittsburgh, a blanket of dust containing approximately 1,950 tons per square mile gradually settles each month throughout the heating season.

In a single day the average human being will breathe approximately 34 pounds of air – more than five times as much as the combined weight of food and water he consumes daily. In breathing that much air, the average city dweller takes into his lungs over a spoonful of dirt each week.

The particle density in the lower atmosphere varies from a minimum value over large bodies of water to a maximum value over large cities and heavily industrialized areas. One of the largest concentrations of particle density occurs over busy airports. Since all inhabited aircraft are air-breathing, and must operate in the environment of the airport as well as in other parts of the atmosphere, measures must be taken to ensure that air pollution does not hinder the operation of the aircraft.

OUTLINE OF THE FUNCTION OF AIRCRAFT FILTERS

In the operation of aircraft fluid systems the particle size of most concern will be in the range of 1 to 100 microns. Generally speaking, fluid systems can be adequately protected from damage by large particles by the use of wire mesh screens of appropriate size, but the presence of a relatively large amount of quite small particles is sufficient to produce malfunctioning of the sophisticated servo-control valves encountered on present day high speed aircraft. Valves of this type operate largely without seals of the standard type and depend upon the low clearances and the finely lapped surfaces of the moving parts to keep the internal leakage within acceptable limits. Internal leakage is present as long as the system is pressurized and the presence of large amounts of contaminant in the small size range can cause "silting up" of the valve to a point where the response of the system could be reduced to a dangerous level for the operation of the aircraft and, in the case of a guided missile, produce an aborted mission.

†Paper read at the Mid-season Meeting of the C.A.I. in Edmonton on the 19th February, 1960.

*Aircraft Hydraulics Group Leader

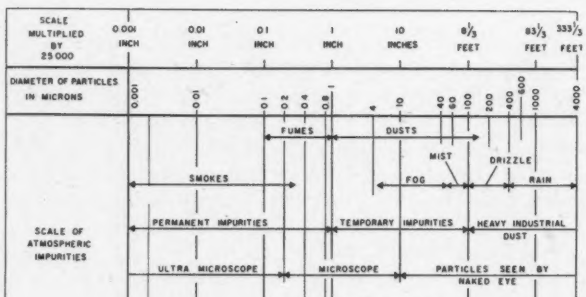

Figure 1
Scale of atmospheric impurities

Some idea of the task confronting the filter designer can be gained by referring to Figure 1[1]. As can be seen on the top line, if we multiply the particle size by 25,000 we can illustrate in a relative way the size range of the particles which the filter must handle. The range is from about 0.5 inch to over 8 ft! The possibility of achieving this in a single filter is very remote, and present day practice is to use two or three stage filtration.

Current aircraft fluid systems use one or more "clean-up" filters with large dirt-holding and flow capacities and install individual filters with a low micron rating immediately upstream of each control valve. The Avro Arrow incorporated a g-restrictor valve in its system which contained metering orifices of 0.004 inch in diameter with an individual filter to protect this contaminant-sensitive component.

The increase in aircraft performance, which brought about the use of fine filtration, also imposed higher operating temperatures on the system. Such time-honoured filter materials as felt and impregnated paper had to be discarded in favour of sintered powdered metals and sintered and unsintered woven wire mesh elements. It became necessary to rate these elements with regard to the size range of particles which the various media would transmit.

CHOICE OF METHOD

Attempts at measuring the pore size of the filter material by preparing sections for microscopic examina-

tion have not proved very fruitful to date. The difficulties involved with such a material as woven wire mesh can be imagined. At best this technique would only offer sampling of the medium in a very minute way which could not be considered to be statistically significant.

One method[2], however, by which the largest pore size and the mean over-all pore size can be calculated, deserves some attention. It is based on the theoretical relationship between the bubble point of a single round capillary and the diameter of the capillary, viz,

$$\text{Bubble point} = \frac{4\gamma \cos\theta}{\text{Diameter of Capillary}}$$

where γ is the surface tension of the fluid and θ the angle of contact.

The method measures the pressure at which the first bubble appears when air pressure is applied across the filter medium while it is immersed just under the surface of a fluid. From the differential pressure in inches of water when the first bubble appears, the approximate size of the largest pore can be calculated. By gradually increasing the pressure differential, the mean over-all pore size can be approximately determined. Values obtained by this method do not correlate too well with the values obtained from measuring the size of particle which will pass through the filter. The initial bubble point however can be a useful quality control artifice for locating the largest pore in the filter medium.

A filter reduced to its simplest form would consist of a flat plate honey-combed with equally sized holes – the diameters of which would correspond with the desired cut-off of the filter. If such a rigid member were confronted with perfectly round spheres of a rigid material, there could be no question as to the maximum size of particle which the filter plate would allow to pass through. If the filter element to be rated were regarded as an approximation of the "filter plate" and rigid spherical particles of a sufficiently large size range could be obtained, the filter element could be given a size transmission rating in a fairly fundamental way by using principles and methods borrowed from the techniques of fine particle measurement.

Glass spheres or beads, obtainable commercially, offered a number of advantages, the chief of which were:

(a) The material would be inert.
(b) The use of spheres would avoid the counting of irregularly shaped particles.
(c) All non-spherical particles could be regarded as tramp contaminant.
(d) The sizing and counting of the spheres could be readily carried out by the use of photomicrographs; the use of the microscope being considered as the most fundamental method for fine particle analysis.

In determining what the size distribution our proposed test contaminant should have, a search of the literature proved to be of little benefit. The following quotations will illustrate the point:

(a) From Reference 3, published in the United Kingdom, we read, "It would appear however that the great majority of naturally occurring and airborne dusts, ground powders and aqueous mists in equilibrium with the water vapour of the dispersing gas have size distributions which are approximately Gaussian."
(b) From Reference 4, published in the United States, we read, "It is first necessary to point out that so-called Gaussian or normal distributions of particle sizes rarely if ever occur. Actual distributions are skewed rising relatively sharply at the lower end of the size spectrum and then tapering off as particle size increases. There is usually a smallest and a largest particle depending on the method used."

From analysis of the hydraulic fluid it was found that the particles contained in the fluid did in fact have a skewed distribution rising sharply at the lower end of the size range and tapering off as the size increased. As this agreed with our view that the test contaminant should have a distribution which would give approximately equal areas for all sizes, this principle was adopted.

In setting up the test standard, it was found that all the obtainable glass beads were deficient in the small size range and it became necessary to set up a laboratory method to obtain spheres in the 1 to 10 micron range.

A few words about the method used to fabricate the spheres may be of interest. Crushed glass particles were tumbled in small ball mills until a sufficient amount of small particles were obtained. The time required to do this was obtained by determining the relation between tumbling time and particle size. The larger particles were sieved out and the remainder propelled by air pressure through an oxy-hydrogen flame in which the particles were fused into spheres. The output of spheres from the hydrogen torch was sent through an air elutriator which discarded particles above 10 microns.

The 1 to 10 micron spheres were mixed with the commercially obtained glass beads in the size range from approximately 8 to 50 microns in the proportion that would produce approximately equal areas for all sizes. This became our standard test contaminant.

TEST METHOD

The most important single feature of the test method evolved was the sizing and counting procedure adopted. This will now be described in detail.

A sample of the contaminant was placed on a glass slide and dispersed with isopropyl alcohol in order to produce an even layer and to get rid of electrostatic charges. Selected fields were photographed through the microscope and at the same time a graticule inscribed in divisions of 0.01 mm was also photographed with the same degree of magnification to obtain a calibration factor for sizing the particles. Enlargements were then obtained of the photographs of both the glass spheres and the calibration graticule. Using the scale factor obtained from the calibration photograph every sphere was measured and counted.

As it was not possible to bring into focus the entire size range with a single degree of magnification each slide was photographed under magnifications of 100× and 200×. Since the size of the field viewed through the microscope varies inversely with the degree of magnification, it was necessary to obtain four photographs for the 200× magnification for every one of the

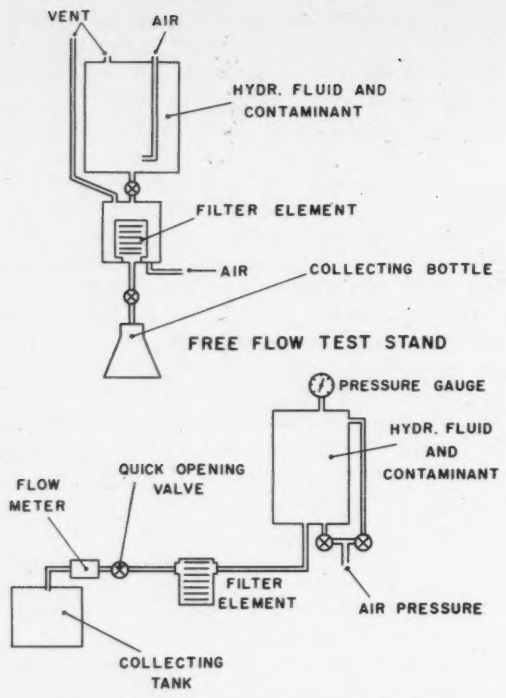

Figure 2

Test apparatus

100× in order to sample equal fields for the two degrees of magnification used. With the addition of photographic enlargement, the effective magnification was increased to approximately 200× and 400×. The particle counts thus obtained were plotted with the abscissa as the mean value of the discrimination band, which was 2.35 microns for the 100× magnification and 4.7 microns for 200× magnification. The ordinates were plotted as the percentage of each size to the total number of particles counted.

In order to assess possible operator bias, the same set of photomicrographs were counted by six different people and the results were plotted for comparison. In all cases except one, the results were well within the probable counting error. In the single exception it was obvious that the operator lost the ability to discriminate below about 7 microns.

Armed now with the useful measuring tool of the standard contaminant with a known size distribution, apparatus as shown in Figure 2 was set up – the upper configuration being used for free flow tests and the lower for testing under different rates of flow.

Clean hydraulic fluid was obtained by filtering through a 0.45 micron membrane filter. Samples of the fluid were checked for cleanliness by centrifuging at 1000g for 30 minutes and inspected for tramp contaminant. A weighed amount of the standard contaminant dispersed in isopropyl alcohol was added to several gallons of the clean fluid and sent through the test filter. The effluent downstream of the filter was collected and centrifuged in successive stages decanting the supernatant fluid at each stage. In the final stage isopropyl alcohol was used and, as in the case of the sizing of the original contaminant, the final dispersion was collected and samples deposited on glass slides and the sizing and counting procedure carried out as before.

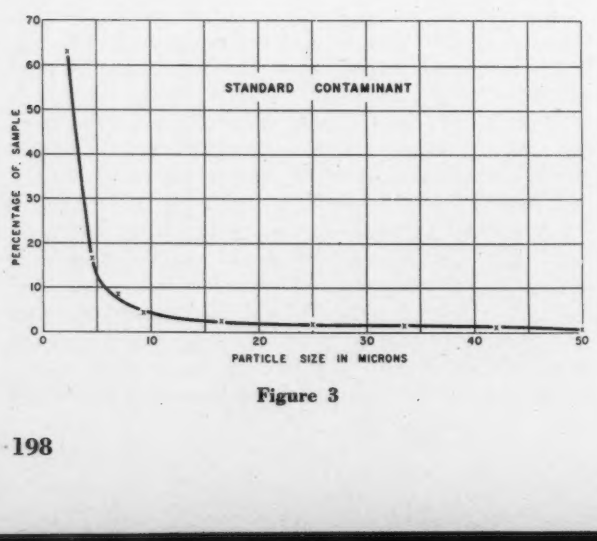

Figure 3

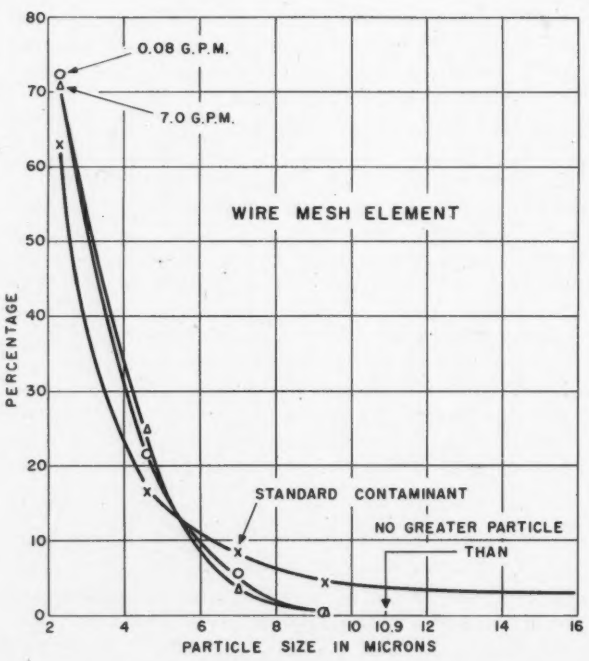

Figure 4

The distribution curve representing the downstream contaminant now can be compared with the upstream contaminant distribution curve, making it possible to assign a rating to the filter element which can be related to the frequency and the size of the particles which the media will transmit.

PRESENTATION OF RESULTS

The test results are given in graphical form rather than sets of tables, in order to convey a visual picture

of the size distributions involved. Arithmetically divided scales are used to enable the contrast between the upstream and downstream contaminant distributions to be presented as simply as possible. Size frequency curves, such as we have used, may be considered as smoothed out histograms. The curves are designed to represent the entire population of particles from which the samples are taken. If the area under the curve is finite and set equal to one, then the area between any interval on the abscissa and the curve above this interval is equal to the probability that a particle chosen at random from the population will have a particle size within that interval[5].

Figure 3 shows the curve representing the standard contaminant size distribution. The larger end of the size range was not carried beyond 50 microns as it was not necessary for our purpose.

Figure 4 shows the curve representing the size distribution of that portion of the standard contaminant which came through a sintered woven wire mesh filter,

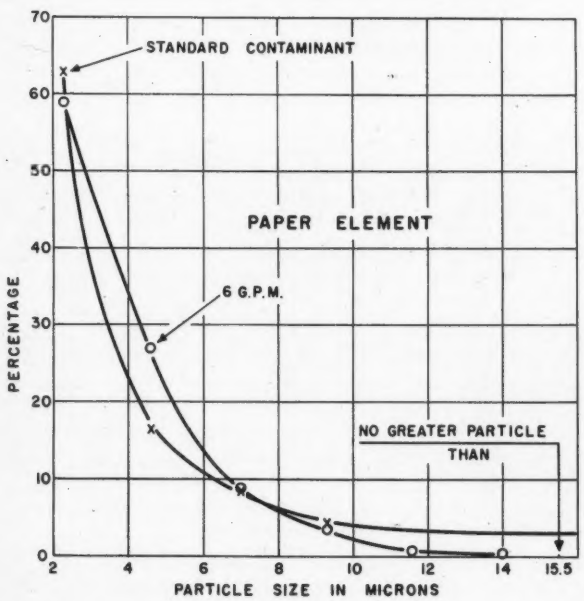

Figure 5

superimposed on the lower end of the contaminant curve. The arrow indicating "no larger particle than" is placed conservatively at approximately 11 microns, an interval of 1.7 microns larger than the size of the largest particle observed, as an indication of the probable limit of the measurement accuracy.

The tests on this filter were carried out at two different rates of flow, 0.08 gpm and 7.0 gpm and, as can be seen, the results show this element to be relatively insensitive to flow rate. The most important feature to note is that the filter element does have a definite cut-off value and can be given a rating in accordance.

Figure 5 shows the results of the test carried out on an impregnated paper element which has a nominal rating of 10 microns. The test was carried out at the rate of flow for which the filter was designed. The

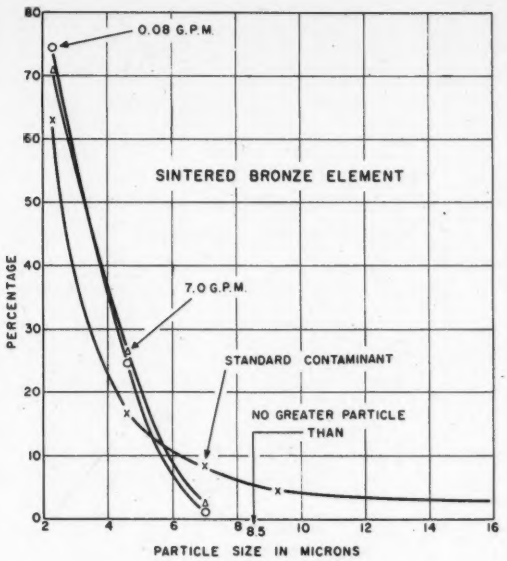

Figure 6

results of this test indicate that the particular paper element used was of a very high quality as this medium is not considered to have a definite cut-off at this value.

Figure 6 shows the same type of comparison as in the previous figures for a sintered bronze element; the cut-off value assigned by our method is quite low, i.e. 8.5 microns although the filter had been rated as a 4μ absolute by other methods.

Figure 7 shows the results of tests on a non-airborne type of sintered bronze filter. The curve shows the characteristics of this type of filter in a very illuminating way. Such a filter would normally be rated at approximately 10 microns but as can be seen there is no clearly defined cut-off; a small percentage of quite large particles still pass through the filter. This exhibits, in quite a remarkable manner, the difference in the degree of quality control maintained for airborne and non-airborne equipment.

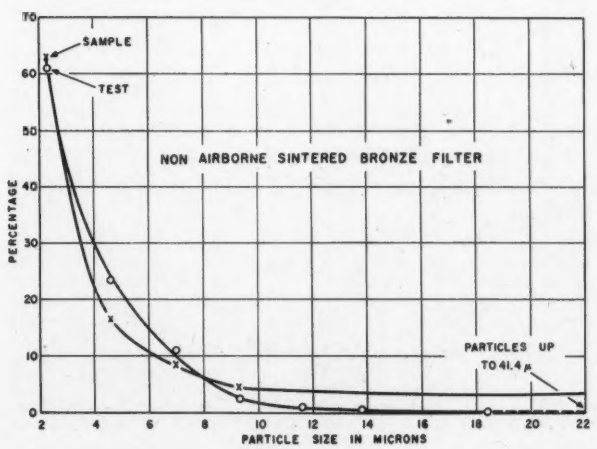

Figure 7

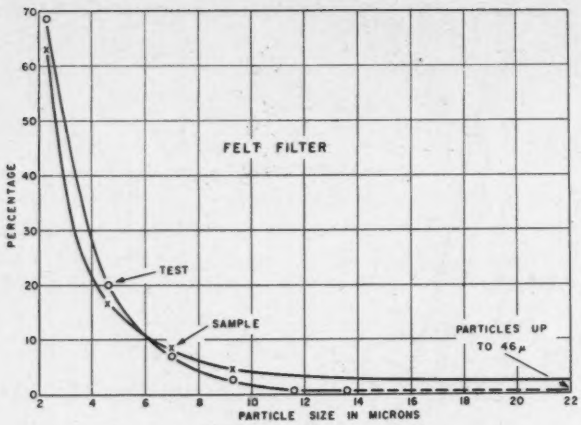

Figure 8
Felt element

Figure 8 shows the results of tests on an airborne type felt element. As one would expect with this type of material, no definite cut-off is exhibited. As can be seen from the curve, the filter does extract approximately 98% of all particles 10 microns and larger but allows the passage of a small number of particles as large as 46 microns. This does not necessarily indicate that this is a cut-off value for the element; if the test contaminant had particles larger than 50 microns, some of those larger particles in all probability would have found their way through the filter.

Figure 9 gives a visual example of what occurs in the filter; on the left is shown the test contaminant before contacting the filter and on the right hand side the portion of the contaminant that passed through the filter.

The largest particles in the test contaminant are approximately 0.002 inch in diameter, while the largest particle observed in the filtrant is 0.00028 inch in diameter.

Figure 10 shows the particle size and shape of standard aircraft test dust which is used for the nominal rating of aircraft filters as defined in specification MIL-F-5504.

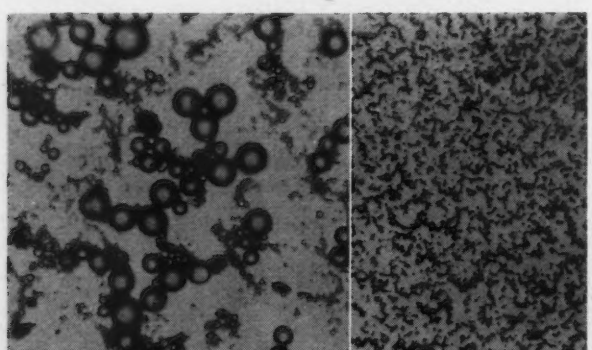

Figure 9
Comparison of contaminant before and after filtration

An appreciation of the additional complexities involved with the use of irregularly shaped particles can be gained, when one considers the fact that not only must shape factors be taken into consideration but the orientation of the particles must be considered as well.

OBSERVATIONS ON THE CHARACTERISTICS OF SEVERAL DIFFERENT TYPES OF POROUS MEDIA

Matted felt, impregnated paper and sintered powdered metal elements can be classed as depth media and share the common property of a relatively large dirt-holding capacity. Sintered woven wire mesh elements on the other hand are a close approximation to the filter plate mentioned earlier and are less able to filter out large quantities of contaminant without increasing the differential pressure across the element beyond acceptable levels. The high strength of this material makes it possible, when properly fabricated, for the element to withstand extremely large pressure differential values; this, plus the favourable strength weight ratio, makes it attractive for aircraft use. Since the material is capable of withstanding the full working pressure of 3,000 psi, normally used in aircraft hydraulic systems, it is customary to incorporate pressure differential indicating devices which, when set at the required value, signal the necessity of removing the element for cleaning.

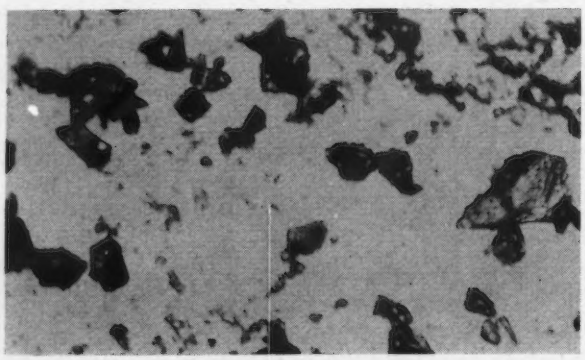

Figure 10
Standard aircraft dust
(note variation of particle size and shape)

The sintered powdered metal elements do not possess sufficient strength to withstand large differential pressures without increasing the envelope dimensions of the filter and imposing a weight penalty on the aircraft. It is customary to incorporate a by-pass valve in the filter housing of these elements, in order to avoid destruction of the element by undue increase in the differential pressure. The large dirt-holding capacity of this material can perhaps best be used to advantage in the capacity of a general clean-up filter for the system. The degree of filtration is for all practical purposes insensitive to the rate of flow for the rigid metallic elements, and their ability to withstand high temperature conditions is a property of value for high speed aircraft.

The felt and the paper elements due to their temperature limitations are not capable of being utilized to advantage on high temperature systems, although their light weight and low cost are advantages which will ensure their continued usage in aircraft systems wherever practicable.

DISCUSSION OF METHOD ACCURACY

Possible inaccuracies encountered in the method described can be classed as:

(a) limits of the accuracy of the equipment used,
(b) inaccuracies due to the observer, and
(c) the probable statistical errors.

Concerning the equipment

The choice of the use of optical microscopy for sizing the particles was made on the basis that it is generally acknowledged as the only method by which a size distribution may be obtained in absolute terms[6]. Some of the limitations of the microscope however must be taken into consideration.

In photomicrography it is the microscope that matters, the camera merely substitutes a sensitive plate for the human eye. The depth of focus becomes a factor of great importance therefore, as the photographic plate will only record that which is in sharp focus in its plane at one time. The depth of focus is inversely proportional to both the numerical aperture and the degree of magnification and falls off very rapidly since both the NA and and the magnification increase together[7].

The NA determines the degree of resolution, the limit of which is given by the fundamental formula

$$d = \frac{\lambda}{2NA}$$

where d = limit of resolution
λ = wavelength of light used
NA = mean numerical aperture of the objective and sub-stage condenser.

As we were required to photograph the spheres over a considerable size range, it was necessary to achieve the best compromise between the degree of magnification, the value of the numerical aperture and the depth of focus.

The focal depth achieved enabled the full size range to be photographed with only two different degrees of magnification. Further increase in the magnitude of the scale factor was achieved by enlarging the photomicrographs.

Since the field viewed through the microscope varies inversely with the degree of magnification, it follows that the greater the magnification the smaller the field and the smaller the field viewed the greater the possible sampling error. By viewing equal fields for both the degrees of magnification used, no discrimination should result from the use of the different degrees of magnification, and the errors involved could be expected to be consistent over the complete size range.

Concerning measurement

The size of the class intervals used was dictated by the limit of accuracy with which the particles could be measured on the photomicrographs. It was not considered practical to attempt to size the photo-scale particles to a closer tolerance than ± 0.5 mm. The calibration factors derived from the photographed graticule were 1 mm = 2.35 microns for the 200× magnification and 1 mm = 4.7 microns for the 100× magnification.

Thus particles were counted in groups 2.35 microns wide up to approximately 10 microns and the remainder, which were in the range from 10 to 50 microns, were counted in groups 4.7 microns wide, since no further appreciable accuracy would be obtained by counting this latter size range in narrower bands.

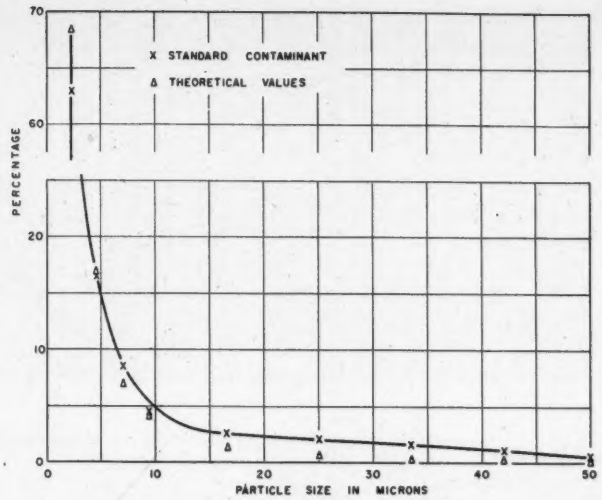

Figure 11

Theoretical and actual distributions

Figure 11 illustrates how closely the actual distribution curve, derived from a number of samplings of the test contaminant, agrees with the theoretical values shown, which represent equal areas for all sizes of the complete size range.

Concerning statistics

By the use of statistical sampling theory, with which we are able to draw inferences concerning a population or a universe from a randomly drawn sample, it is possible to attach a probability value to the frequency distribution with a fairly high degree of confidence. In the case at hand, the population or universe is represented by the entire amount of our test contaminant, and the randomly drawn sample is that portion of the test contaminant which is viewed through the microscope. By the use of the mean of the frequency distribution of the sample, it is possible to make a probability prediction concerning the distribution of the population. It has been shown by investigators that the distribution of means from nearly any universe is practically normal. Thus it is possible to reduce the sampling data of our skewed distribution to standard units by a mathematical transformation and derive a probability value for the relation of the universe to the sample[8].

From the average derived from a number of samples of the test contaminant in which 6,817 individual particles were sized and counted, a sample mean of 5.11 microns was established. By the transformation function referred to it was possible to calculate, within a probability of 95%, that the mean of the population was within ± 0.15 microns. From a statistical point of view this represents a reasonable level of confidence.

CONCLUSION

The individual sizing and counting of small particles by any application of optical microscopy is a tedious and time-consuming procedure. Many efforts have been

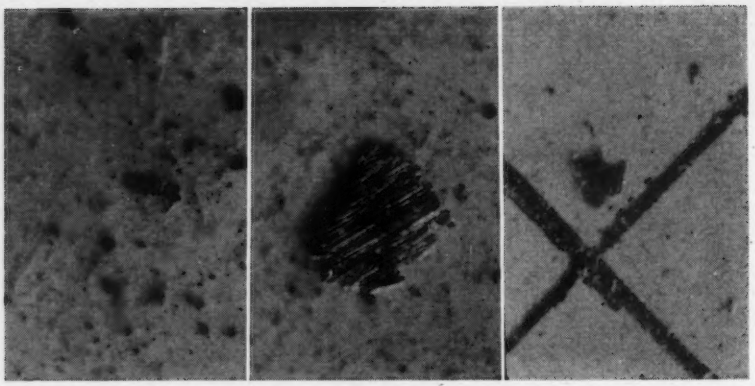

Figure 12

Example of contamination found in an airborne system

directed towards developing instrumentation for the automatic determination of the size and frequency of small particle distributions. Automation principles, currently known to be under investigation, can be divided into two main classifications: the first of which utilizes electronic means to size and count particles scanned, by various methods, through an optical microscope, and the second uses electronic means to measure particles in the fluid itself as it is directed through a small aperture. Calibration of this latter type is dependent upon the use of particles the size of which has been determined by optical microscopy.

Other methods of particle size determination, such as sedimentation and air elutriation, refer their results to comparable results obtained by optical microscopy to obtain a measure of the accuracy of the particular method used.

It can be stated that no known method of fine particle measurement can claim a greater accuracy than that obtained by the intelligent use of the microscope for the particular size range which we have been considering. The penalties in time and tediousness which must be paid in using the microscope are small compared with the confidence with which the results may be regarded.

Lest it be thought that the complexities of fine particle measurement and data presentation have been laboured to an unnecessary length, the above photomicrographs are offered as evidence of the necessity for controlling the contamination level in aircraft fluid systems (Figure 12). The contamination shown in these photomicrographs was filtered from the fluid contained in an aircraft flight control component taken from a system which was protected by a filter rated at 4 microns absolute. While some of the metal chips and rubber particles were undoubtedly generated by the system itself, the sand particles, particles of paint pigment and several types of resin that found their way into the system could not have been system generated.

The SAE A-6 Aircraft Hydraulics Committee's Contamination Control Panel has defined "clean fluid" in the as-received condition from the oil vendor as that conforming to the requirements shown in Figure 13. It is perhaps surprising to note the amount of contaminant above 100μ. The Wright Air Development Center in the United States has stipulated that aircraft hydraulic fluid must be delivered containing no particles greater than 100μ. The super clean fluid levels were established by agreement among all the processors, users and filtration experts involved, as representing the maximum obtainable, using the ultimate in filtration techniques available at the present time.

While it is true, as many aircraft engineers are quick to point out, that we do not fly glass beads around in our aeroplanes, the use of a test contaminant with a known size distribution comprised of spherical particles only, does enable the filter specialist to make accurate predictions concerning the performance of most types of filter media. The size of the largest particle transmitted, whether or not an absolute cut-off exists, the relative distribution of the particles transmitted through the medium and a measure of the dirt-holding capacity can all be determined by precise laboratory tests with the use of a test contaminant, developed by the methods described in this paper.

SIZE RANGE (MICRONS)	AS RECEIVED FROM FLUID SUPPLIER	SUPER CLEAN FLUID
5 - 15	100,000	590
15 - 25	40,000	150
25 - 50	10,000	100
50 - 100	1,000	27
> 100	500	13

Figure 13

Contamination levels based on 100 cc sample

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THE DEVELOPMENT OF THE STOL AIRPLANE†

by A. F. MacDonald*

The De Havilland Aircraft of Canada Limited

THIS is indeed an age of high speed air transportation in which we live today.

Great jetliners hurtle across oceans and continents at speeds of 500 to 600 mph. In the sphere of military aviation, we are on the verge of 2,000 mph speeds. Satellites have been clocked in outer space at speeds in excess of 18,000 mph.

Ever since man first solved the problem of getting the earliest flying contraptions airborne, the emphasis in aircraft design has been towards greater and ever greater speed.

But I am going to talk about an entirely different kind of airplane – the kind that flies low and slow.

There are still a great many million more square miles of primitive areas in the world in which we live than there are densely populated areas. These undeveloped territories must be served by airplanes which are capable of operating out of tiny lakes and rivers, small fields or short jungle landing strips. Your high speed jetliner can operate only over highly organized airways systems served by multi-million dollar super airports with 10,000 to 12,000 ft runways. This champagne-flavoured age of jet travel is for the chosen few who can afford the speed of sound in luxury jetliners, but it's not for Joe Blo and his Missus who live out in Birds Eye Centre, Saskatchewan.

STOL AIRCRAFT

The kind of airplane that I am going to talk about requires no costly or complicated base from which to operate. It is simple and rugged in construction. Fitted with seaplane floats in summer, it can moor up to any rough log dock or shoreline. In winter it stands out on the ice unsheltered. As a landplane, it must be able to operate from any short stretch of roadway, or from tiny landing strips bulldozed out of the jungle. This type of airplane is no "Hangar Queen". It may never see the inside of a hangar from one year's end to another.

The STOL airplane is a product which had its origin right here in your own native Canada. The first demand for an airplane of this kind originated with the bush pilot. He needed a seaplane capable of taking off with big loads in short distances out of the many lakes and rivers with which our undeveloped north country is so generously endowed.

In an area where no suitable roads exist for heavy transport, the Beaver was able to use the sand beach to haul a cargo which was salvaged from a river barge by ox cart.

The first bush planes were mostly landplanes, imported from Britain and the United States and improvised for the bush operator's needs by fitting seaplane floats and winter skis. Performancewise, they left much to be desired.

Back about 1929, a few pioneer organizations turned their hand to the design of aircraft specially suited to our Canadian requirements. Among these were the Fairchild 71 and 82, Vickers Vedette, Fleet Canuck and the Noorduyn Norseman.

Beaver

In 1947, my own company, The De Havilland Aircraft of Canada, was in a position to take advantage of the tremendous technological advances which had been achieved by the aviation industry during World War II. These included improved methods of lightweight metal construction, higher engine power outputs and the revolutionary progress that had been gained in design know-how.

A bush airplane was developed called the De Havilland Beaver, in which short takeoff and landing performance was one of the most important considerations in the design.

†Paper read at the Mid-season Meeting of the C.A.I. in Edmonton on the 19th February, 1960.

*Public Relations Manager

A Japanese Antarctic Beaver being blessed by Shinto priests prior to departure for the South Polar regions.

The Beaver is an all-metal, high wing monoplane, very conventional in its design concept. It has a wing span of 48 ft and an authorized gross weight of 5,100 lb. This aircraft is designed to take off in a distance of 560 ft on land, or 855 ft from water. This with zero wind. With a 20-mile headwind, these distances are reduced to a little over 300 ft on land and 500 ft on water. The Beaver achieves this remarkable takeoff performance with a load of 7 passengers and pilot, or three-quarters of a ton of cargo with fuel for 200 miles.

Factors which enable the Beaver to achieve this impressive load carrying takeoff performance are: an engine of 450 hp, giving a low power loading of 11.3 lb/bhp; the use of effective high-lift slotted flaps and the choice of a wing with good aerodynamic characteristics.

Despite its short takeoff and high load carrying capacity however, the Beaver landplane cruises at 143 mph at 66% of power.

So when we speak of the STOL airplane as flying *low and slow*, we are, of course, using the terms in a comparative sense.

Designed originally as a Canadian bush airplane, the STOL Beaver has found a useful application in many other countries where similar lack of airport facilities exist. A few examples are: Rhodesia — where Central African Airways operate a fleet of 6 Beavers out of tiny mountain landing strips which no multi-engine aircraft have been capable of utilizing. Another is Aero Taxi Avianca in Colombia; 15 Beavers provide a service between Bogota and Barranquilla along the Magdalena River, using short makeshift landing strips constructed alongside the villages which dot the river route. Still another is Antarctica. Here, 7 countries are using Beavers and Otters on one of the toughest flying operations ever undertaken. The Beaver literally "made a name for itself" in Antarctica; Beaver Lake, Beaver Glacier and Beaver Island were all named after it.

12,000 natives in New Guinea swarm around a Beaver which has just landed on a strip the natives had trampled down.

Built originally to operate from Canada's north country lake areas, the Beaver fulfilled perhaps its most vital mission as a landplane with the United States Army in Korea. Designated the L.20, it was used as an ambulance plane for the evacuation of wounded, as a transport plane for the movement of men and supplies into forward battle areas and as a command plane for the transportation of high ranking officers. In this role it became known as the "General's Jeep" and was used by General Van Fleet, General Ridgeway and General Mark Clarke to visit front line positions. It was also the aircraft chosen to transport President Eisenhower on his tour of the Korean Front in 1955.

A US Navy Otter unloading supplies at McMurdo Sound, Antarctica.

During the latter stages of the Korean War, a force of 50 Beaver L.20's carried out an operation known as "teenie weenie air transport". This operation made military history. It proved to be the first application of the use of STOL airplanes as "Flying Trucks" to provide rapid mobility for infantry ground forces in modern warfare.

The Beavers airlifted an entire regiment of combat troops over a mountain range in half a day. The same movement would have taken 3 days for motor truck convoys to accomplish on the roads — provided, of course, there were any roads.

Otter

Now we come to the Otter. This is simply a "King Sized" Beaver — exactly similar in performance but with roughly double the load of the Beaver.

Our original thinking was to build a scaled-up version of the Beaver. But we couldn't find an engine to fit the formula. The Otter is fitted with the 600 hp R1340 geared Wasp engine. This gives it a higher power loading than the Beaver — 13.3 lb/bhp versus 11.3. To offset the lesser power available for takeoff, we went to a more elaborate system of slotted flaps. The Otter grosses 8,000 lb and carries 9 to 11 passengers with crew,

or an equivalent cargo payload of a ton and a half with fuel for 200 miles.

First of all, a word about the use of the STOL Otter by the US Army.

The threat of atomic weapons has completely changed the whole army concept of war. It is now no longer considered prudent to concentrate large bodies of troops in any one location since an atomic bomb could destroy an entire Army Corps. The new idea is one of small units, widely dispersed, and capable of lightning fast mobility. Rapid mobility can be accomplished by one means only – the airlift – and this is how the Canadian Otter came to be adopted by the US Army.

Designated the U1-A it has been purchased in quantities to serve as a "Flying Truck" for the movement of American combat troops into forward battle areas.

When you consider that it took 2½ million motor vehicles to move the US Army in World War II, the production of STOL aircraft in any war of the future could well run into astronomical figures.

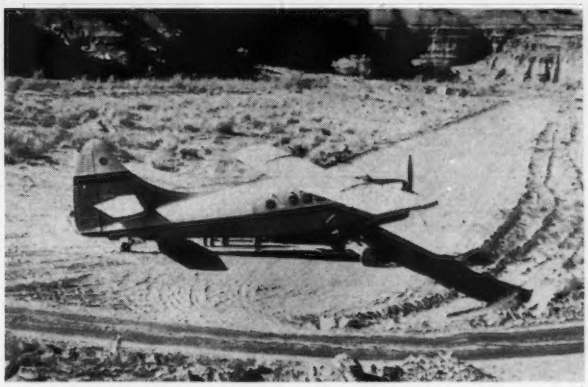
Army Otters moving ammunition and supplies into a rough temporary field in the combat area.

A company of Otters in the US Army consists of 21 aircraft. During Operation "Call and Haul" at Fort Riley, Kansas, in 1957, five platoons of the 2nd Otter Company succeeded in moving 305 fully equipped combat troops of the 16th Infantry Regiment (plus a substantial quantity of recoilless rifles and mortars) into a forward battle airstrip, a distance of 35 miles, in an 80 minute period. Subsequently, during the same exercise, 10 Otters in two platoons shuttled 20 tons of ammunition and supplies into an improvised strip in a 45-minute period. Operation "Call and Haul" was organized to test the ability of STOL army aircraft to provide immediate airborne support in a situation requiring instant action on short notice.

With its smaller STOL companion, the Beaver, the Otter is performing many and varied workaday chores in some 62 different countries throughout the world. In the South Pacific, Philippine Airlines use a fleet of Otters to serve a network of isolated villages located deep in jungle territory.

A typical example of the time and cost saving by STOL aircraft is a journey by Otter in the Philippines which takes 20 minutes and costs 9 pesos. The same trip by motor bus takes 9 hours and costs 40 pesos.

In Northern Canada, the STOL aircraft has filled a vitally important role as an empire builder. The Rayrock Mine in the Northwest Territories, for example, was built almost entirely by airlift and, during the brief span of the uranium mining boom in Canada, utilized Otters



Transporting mining equipment in and out of a uranium mine in Colorado.

of Wardair Limited to fly its supplies in and its concentrates out.

39 Otters of the RCAF perform search and rescue operations across Canada from coast to coast and far into the vast lonely stretches of the Arctic – beyond even the DEW Line. These will be augmented by an additional 27 Otters on order for the RCAF at the present time.

DHC-4 Caribou

The Caribou is our latest STOL design project.

This is a transport aircraft in the DC-3 weight category which grosses 26,000 lb. It is fitted with two R2000 engines of 1450 hp each. The design take-off distance is 540 ft with still air. With a light 10 to 12 mile wind it gets off the ground in approximately 300 ft – about the length of the Argos' new football stadium in Toronto's Exhibition Grounds. It is the first airplane in the world in its weight category designed to take off and land in such a short distance.

The Caribou civil transport carries 30 passengers. The military version will seat 32 combat troops or 2 army jeeps. The cargo payload varies from 3,000 to 6,500 lb, depending on range.

The original concept of the DHC-4 Caribou at De Havilland's was that of a "twin-engine Otter", designed around the Otter's two 600 bhp engines, having a fixed gear and a gross weight of around 13,000 lb. But when both STOL and transport category requirements for engine failure on takeoff had to be realized, the case for the small twin-engine aircraft proved a rather hopeless one. It could boast scarcely more in the way of payload than its single-engine counterpart.

The Otter being used in the service of experimental Decca sites in the Arctic archipelago.

Successive design studies pushed the twin-engine STOL concept weight up to 22,000 lb, 24,000 lb and finally to 26,000 lb. Power requirements increased from engines of 600 to 1200 bhp and eventually finalized in the 1450 hp P & W R2000's. These were considered after two years of intensive design study to be minimum requirements for a twin-engine transport airplane that could meet CAR-4B requirements and still achieve better than average operating economy.

Deliveries of this Canadian designed and manufactured aircraft to the United States Army began in October 1959.

STOL RESEARCH

For four years a research program conducted jointly by a team of De Havilland aerodynamicists and the Defence Research Board has been quietly under way at DHC's Downsview facility[1]. An Otter, fitted with an unique system of very powerful enlarged area slotted flaps combined with some unusual features for the Otter, such as leading edge flaps, slotted elevators, a butterfly tail and boundary layer control etc, has been used as a research vehicle to study the aerodynamic, performance, stability and control problems associated with STOL aircraft.

While the project is definitely not an attempt to develop a new STOL aircraft type, it is significant to note that the research vehicle is able, with flaps 60°, to maintain level flight at 36 knots, and that satisfactory stability has been achieved at this low speed.

It is estimated that landings could be made over a 50 ft obstacle in less than 500 ft, which means a landing

US Army AC-1 Caribou

roll of less than 200 ft, zero wind. With the flap system fitted, the research Otter is lacking sufficient power for very short takeoffs. However, DHC research has shown that with 1000 bhp available for takeoff, the takeoff distance over 50 ft would be approximately the same as the landing distance, namely 500 ft. (This 1000 hp could be provided for instance, with an engine such as the 1250 bhp Gnome which is currently in production and which weighs appreciably less than the R1340 piston engine currently fitted to the Otter.)

This is a DHC-DRB research project in the never-ending search for still shorter takeoffs and landings.

A Caribou pilot's view on touchdown. With a 5 knot wind, the aircraft came to rest 150 ft short of the dark spot in the middle foreground — by actual measurement, a distance of less than 300 ft.

The United States Government is spending vast sums of money on research programs designed to assist the further development of similar objectives. They include such projects as the tilt wing or convertiplane, the ducted fan or flying platform, the deflected slipstream and so on. Like the helicopter, these all involve somewhat complicated mechanical principles and we at De Havillands prefer to direct our efforts into the further development of the simple, rugged type, conventional aircraft which we have been successfully producing for the past decade.

CONCLUSION

I would like to leave with you the prediction that within the next 10 years the STOL airplane will share the limelight with the more spectacular high speed jet transport. Utilizing the principle of high lift at low speed, it should be possible to produce flying buses which will be able to operate profitably at low cost out of small fields located close to the centres of cities and towns which cannot now be served by the airlines.

So the next time you read about sensational new developments in this fast moving age of speed, remember the homely parable about the hare and the tortoise.

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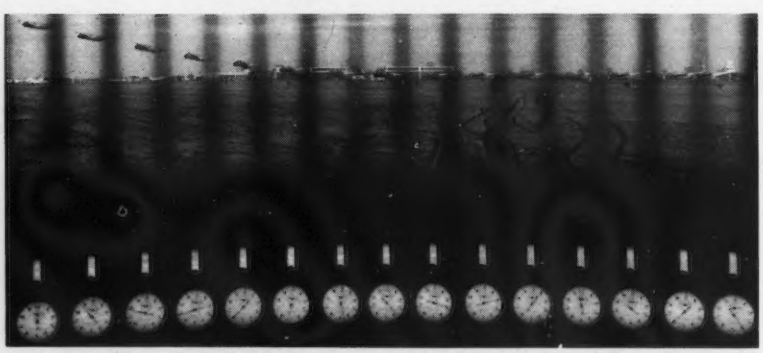


A graphic record of a Caribou takeoff. Conditions were: airport elevation 514 ft MSL; temperature —1°C; wind 2.8 mph, and load 25,840 lb. Takeoff ground roll was 460 ft in 9.3 secs and the distance over 50 ft was 910 ft in 14.2 secs.

THE DESIGN AND TESTING OF AN AIR INTAKE FOR A SMALL SHAFT POWER GAS TURBINE†

by Dr. J. H. T. Wade*

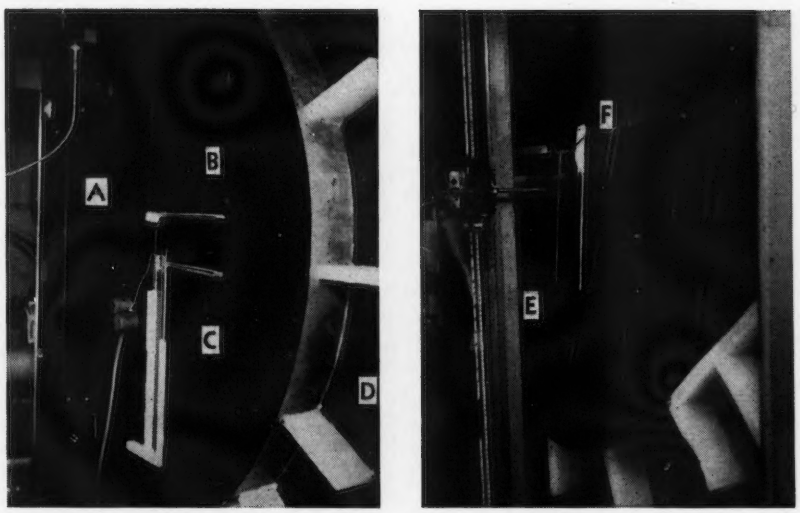
McMaster University

SUMMARY

Three-dimensional electrolytic tank tests were used to predict a proper side wall profile for an axially symmetric intake to be used with a small shaft power gas turbine.

The resultant intake configuration was tested full scale using the Orenda wind tunnel. The aerodynamic tests showed that for a range of throat Mach numbers from 0.175 to 0.417 velocity profiles in the throat were relatively flat with a flow distortion of less than 1.7%. Side wall static pressure profiles showed no signs of incipient separation although due to the intake shape a positive pressure gradient region was found to exist near the throat on one of the walls. The wall velocity profiles plotted non-dimensionally indicated little or no Mach number effect.

A number of pressure traverses taken upstream of the throat showed that the flow distortion increased rapidy in that direction.



a. Front view b. Side view

Figure 1

Preliminary model set-up in an electrolytic tank: A. shore line (model centre line), B. inner wall, C. outer boundary, D. copper wall (upstream electrode), E. measuring probe, and F. downstream electrode

INTRODUCTION

THIS report deals with the design and testing of a three-dimensional axially symmetric intake for a small shaft power gas turbine. The intake was designed to pass a weight flow of 1.4 lb/sec at a throat Mach number of 0.402. Design information for the intake was obtained from three-dimensional electrolytic tank tests. The theoretical performance of the intake was verified by full-scale wind tunnel tests carried out in the Aerodynamics Laboratory at Orenda Engines Ltd., Malton, Ontario.

INTAKE DESIGN

The design of a small centrifugal gas turbine having approximately 75 shaft horsepower produced a requirement for an annular intake, axially symmetric, which would bring the air axially into the eye of the compressor after having turned the flow through 90°. Because of the overhang on the compressor bearings, it was necessary to keep the intake as short as possible in the axial direction consistent with the requirement of a uniform velocity profile at the entrance to the compressor.

The preliminary design was undertaken with the aid of the electrolytic tank. In this approach the tank was tilted approximately 6° to simulate a three-dimensional slice of the intake and the inner wall of the intake was fixed by two straight lines and the arc of a circle. On the outer wall of the model only the size of the throat and entrance were fixed while the actual wall boundary was to be computed. The electrolytic tank models, all non-conductive, were constructed using plexiglass. The non-conductive model, set up in the electrolytic tank for the first study, is shown in Figure 1a and 1b. Figure 1a clearly shows the water shore line corresponding to the model centre line, both electrodes and the inner and outer boundary. In the first test the problem was to force a uniform potential at the throat. This was done by positioning a plane electrode directly at the throat position. The outer wall of the model was composed of two straight sections. These sections clearly enough defined a flow boundary but only in the most elementary way. Actually their purpose was to define a short uniform section at the throat and a second straight (radial) section at the entrance. The outer electrode, simulating the conditions at infinity, had a radius of curvature based on

†Received 18th March, 1960. This work was carried out during the author's appointment with Orenda Engines Limited.

*Associate Professor

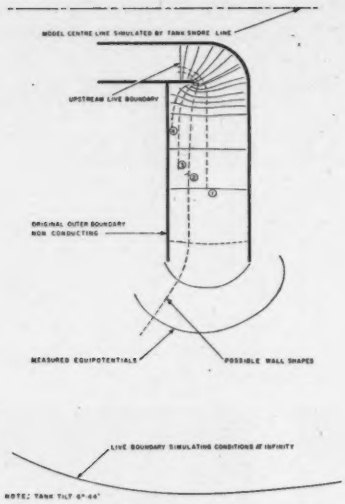
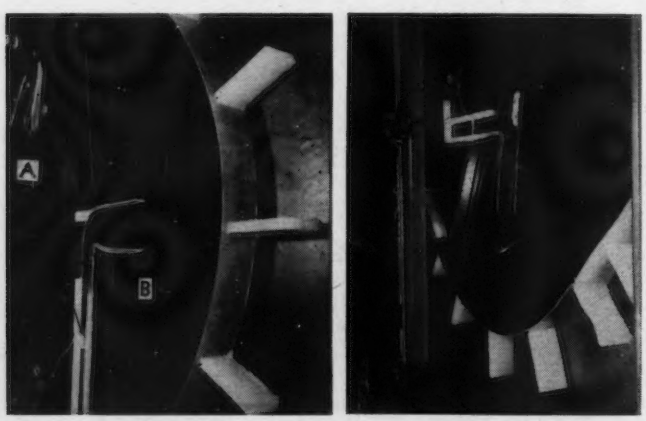

MODEL CENTRE LINE SIMULATED BY TANK SHORE LINE
UPSTREAM LIVE BOUNDARY
ORIGINAL OUTER BOUNDARY NON CONDUCTING
MEASURED EQUIPOTENTIALS
POSSIBLE WALL SHAPES
LIVE BOUNDARY SIMULATING CONDITIONS AT INFINITY

Figure 2
Results of preliminary model tests carried out in the electrolytic tank to establish possible outer wall contours

experience gained in earlier three-dimensional electrolytic tank tests, and was positioned as far as possible from the model consistent with the maximum water height that could be obtained in the tank (about 4 inches).

The results from this first test are shown in Figure 2 where the equipotentials have been plotted from the entrance to the throat. Since the inner wall was defined, it was only a matter of judgment to draw in a number of possible "outer walls" ensuring that in all cases the boundary intercepted the potential lines at right angles. No. 2 boundary, as shown in Figure 2, was considered as a possible shape for the outer wall mainly due to the small scaling factor required to redraw the inner and outer wall to the proper dimensions (considering the eye of the compressor fixed). Figure 3a and 3b show the new model design in the electrolytic tank. The contoured outer wall is clearly seen and it will be noted that for this test the upstream live boundary was removed



a. Front view **b. Side view**

Figure 3
Intake design under test in electrolytic tank (second approximation): A. upstream live boundary — removed from throat position. B. contoured outer wall

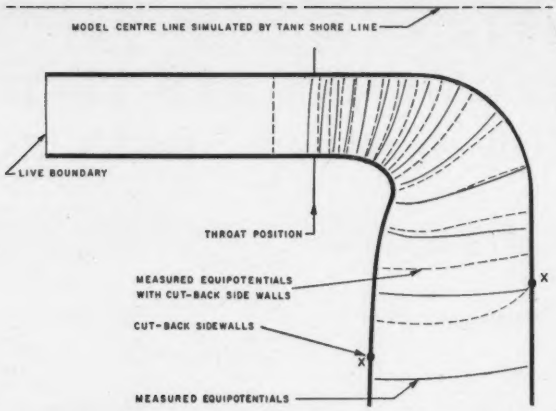


Figure 4
Electrolytic tank model (2nd approximation) showing equipotentials through intake

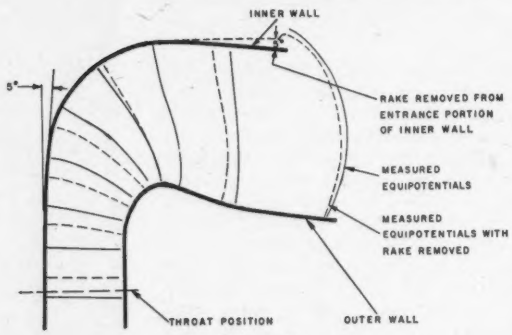


Figure 5
Electrolytic tank model showing the effect on the equipotential lines of tilting the intake 5° from the centre line

from its original throat position and repositioned further downstream so that the equipotentials in the vicinity of the throat would not be too greatly influenced by its presence. The set of equipotentials obtained from this second test is shown in Figure 4. It can be seen that the equipotentials are nearly flat in the vicinity of the throat and therefore dE/dx, which in the electrolytic tank analogy is equivalent to velocity, is approaching the same value on both the inner and outer walls in the throat.

Directly after the test, both the inner and outer walls were cut back to the points marked "x" on the drawing and the positions of the equipotentials re-examined. The cut-back walls had little or no effect on the shape of the equipotentials at the throat as can be seen from Figure 4.

During the latter stages of mechanical design, it was found necessary to provide more room for the upper bearing of the engine. This was done by tilting the entire intake outward, a matter of 5°, leaving, however, the eye of the compressor in the same position as before. The electrolytic tank model was reworked to accommodate this change and retested as shown in Figure 5. A second test on this modified intake was also made with the entrance enlarged slightly, that is, the 5° rake removed from the initial portion of the inner wall.

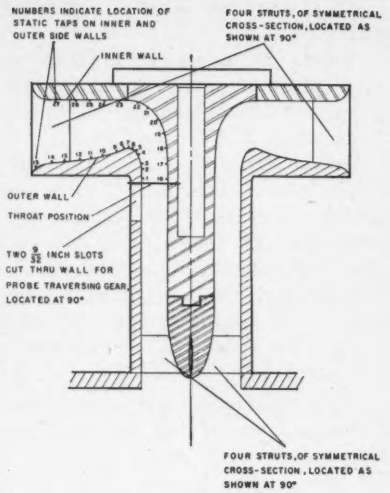

NUMBERS INDICATE LOCATION OF STATIC TAPS ON INNER AND OUTER SIDE WALLS
FOUR STRUTS, OF SYMMETRICAL CROSS-SECTION, LOCATED AS SHOWN AT 90°
INNER WALL
OUTER WALL
THROAT POSITION
TWO 9/32 INCH SLOTS CUT THRU WALL FOR PROBE TRAVERSING GEAR, LOCATED AT 90°
FOUR STRUTS, OF SYMMETRICAL CROSS-SECTION, LOCATED AS SHOWN AT 90°

Figure 6
Details of the intake model (final design) as constructed for aerodynamic measurements

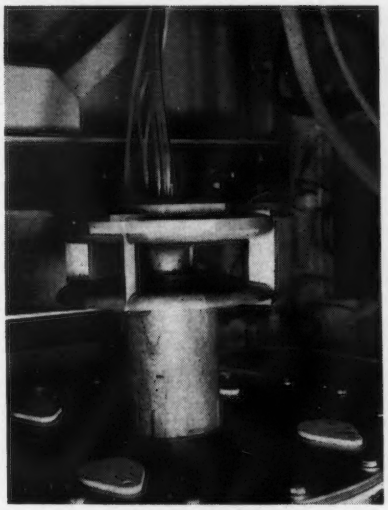


Figure 8
Side view of model intake mounted ready to test on Orenda wind tunnel

Figure 9
Model intake showing general details

As can be seen from Figure 5 these changes in the shape of the inner wall produced little or no measureable change in the shape of the equipotentials in the vicinity of the throat.

It was therefore concluded that this particular intake should be given further study. The equipotentials were quite flat in the throat area and therefore the derivative of the potential with respect to distance in the direction of current flow was constant across the throat area. This ensured, using the analogy, that the velocity would be constant across the throat.

The next step in the test program was to construct the intake full scale (all electrolytic tank tests were carried out twice full scale in order to reduce measuring errors) and obtain some aerodynamic results on the model, particularly to verify the conditions in the throat of the intake.

AERODYNAMIC TESTS

Apparatus

The apparatus for this series of tests consisted of a full scale wooden model of the annular intake the general dimensions of which are shown in Figure 6. The model was fastened to a base plate which in turn was bolted to the wind tunnel in the Orenda Aerodynamics Laboratory, upstream of the wind tunnel fan, in a position normally occupied by the diffuser section. In this position the wind tunnel fan drew the air through the model intake simulating the compressor of the small shaft power gas turbine. The air jet issuing from the test section of the tunnel was deflected away from the mouth of the intake, ensuring that essentially still air conditions existed at the intake entrance. Photographs showing the model mounted on the wind tunnel and illustrating general model details are given in Figures 7, 8, 9 and 10.

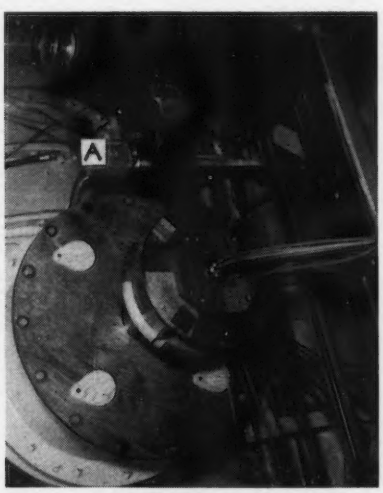


Figure 7
Full-scale intake installed on the Orenda wind tunnel:
A. external traverser

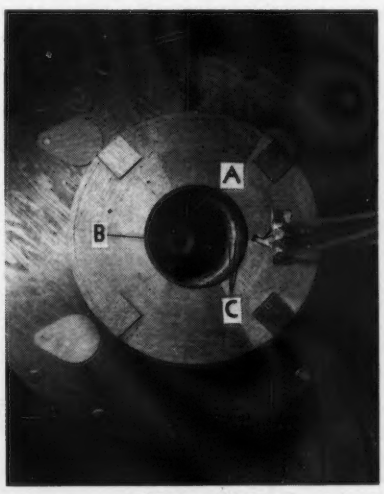


Figure 10
Axial view of model intake showing further details: A. L-shaped pitot-static probe, B. support spider, and C. outer wall static taps

Procedure

With the model in position, an external traverse gear fitted with an L-type pitot-static probe was set up so that a pressure traverse could be made across the throat, as defined in Figure 6. At the throat, it should be noted, the contraction in the intake is complete and both inner and outer walls are parallel with the centre line of the model. Both side walls were instrumented with static taps, 15 on the outer wall and 12 on the inner wall, as shown in Figures 6, 9 and 10, so that static pressures along the surface of the intake could be measured. The tests were carried out at four tunnel speeds covering the range from 2000 to 5000 rpm which corresponded to Mach numbers in the throat of the model from 0.175 to 0.417.

Calculations and results

For each traverse point (r) using the measured ratio p/P a value of $V/\sqrt{T}$ was obtained from the Orenda flow tables ($\gamma = 1.4$). From this latter ratio and a measurement of room temperature carried out near the intake entrance with a standard laboratory mercury thermometer, the local velocity was obtained as a function of r. An average Mach number in the throat was also obtained from the measured pressure ratio. Figure 11 shows the measured velocity profiles for four Mach numbers and it can be seen that the profiles, neglecting boundary layer development, are quite flat. Additional traverses (2) were made to check the shape of the velocity profile near the wall and further assist in verifying the first set of results. An analysis of the six velocity profiles using the definition of distortion level as $1 - V_{min}/V_{max}$ shows that the distortion, neglecting boundary layer, is low and remarkably consistent with little variation due to throat Mach number (1.5% at an average throat Mach number of 0.175 rising to a value of 1.7% at a throat Mach number of 0.417).

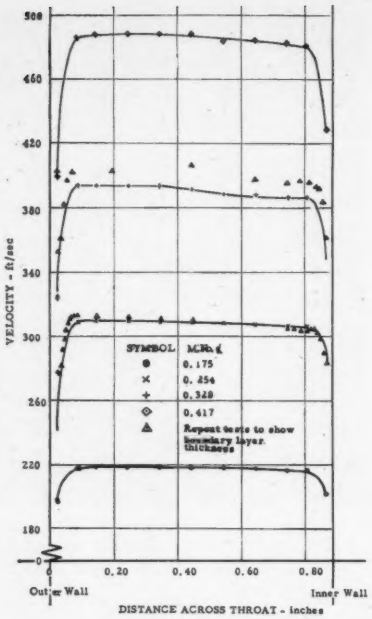


Figure 11
Representative velocity distributions obtained across the throat of the intake during full-scale tests

Figure 12 shows the variation of static pressures along the inner and outer walls as a function of throat Mach number. The inner wall shows a monotonically decreasing pressure, which was to be expected, while the profile along the outer wall is consistent with the shape of the wall and shows no evidence of incipient separation although the pressure gradient is positive for a short distance upstream of the throat. More will be said about this effect later.

The measurement of wall static pressure combined with ambient pressure and temperature enabled one to calculate the velocities along both walls (just outside the boundary layer). These curves are shown in Figure 13 and quite naturally reflect the shape of the static pressure distribution shown in the previous figure. These wall velocities were made non-dimensional by dividing by an average throat velocity V_{throat}, from Figure 11, and replotted as a function of the distance along each wall measured from the throat. The results are shown in Figure 14. Essentially this procedure collapses the wall velocity profiles into a single curve the deviation from which shows the effect of Mach number. The peak velocity in the intake is seen to exist on the outer wall downstream of the point of maximum curvature and to be very nearly 1.2 V_{throat}. There is little or no scatter in the experimental points.

It will be appreciated that the local increase in velocity on the outer wall will prohibit this intake from being used at throat Mach numbers greatly in excess of the design Mach number (0.40). Theoretically, assuming that there will be no departure from the velocity ratio curves shown in Figure 14, it would be possible to have a Mach number of nearly 0.83 in the throat before sonic

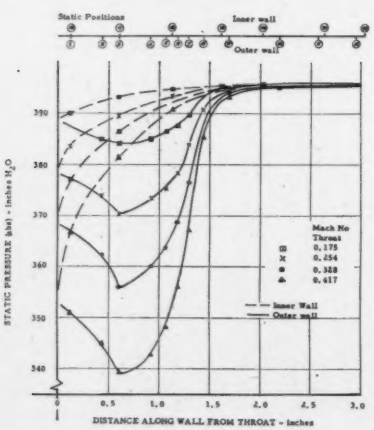


Figure 12
Measured static pressure distribution on the side walls of the intake

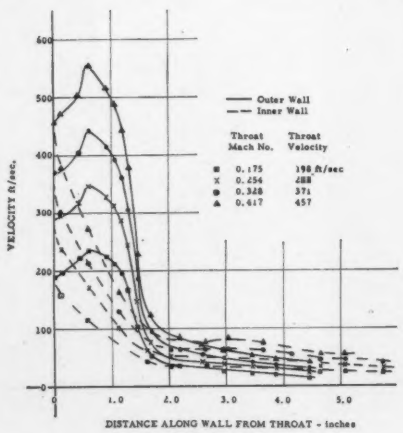


Figure 13
Side wall velocity distributions on the intake — neglecting boundary layer development

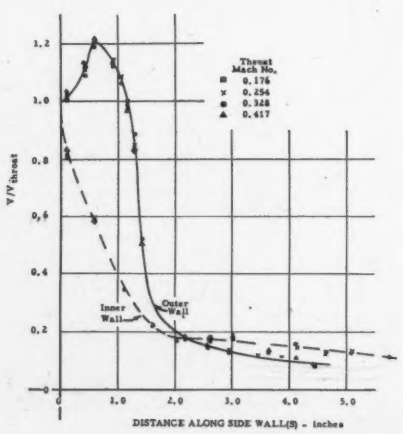


Figure 14
Velocity ratio V/V_{throat} as a function of the distance along the inner and outer walls of the intake

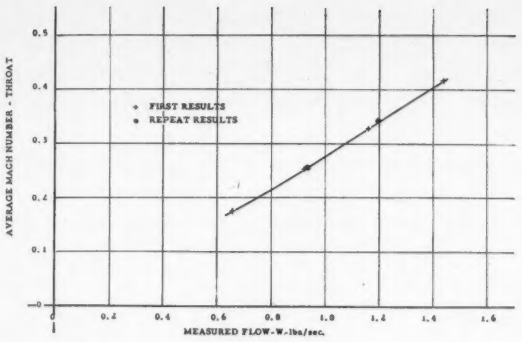


Figure 15
Weight flow (W) obtained from the integration of throat velocity profiles, as a function of throat Mach number

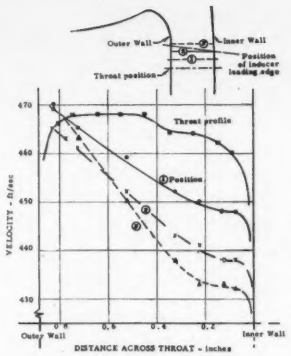


Figure 16
Velocity distributions — measured upstream of the throat showing distortion effects

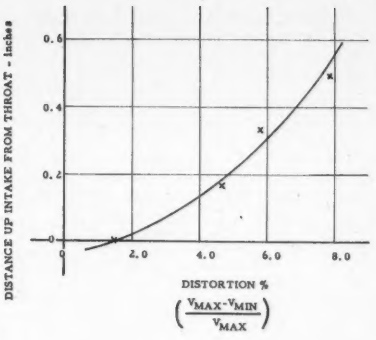


Figure 17
Flow distortion level as a function of the distance upstream of the throat

velocity and the accompanying shock pattern would appear at the point of V_{max} on the outer wall. However, long before this value is reached, the positive pressure gradient existing on the outer wall just upstream of the throat would surely result in flow separation at which time the flow distortion would become excessively high and the intake therefore unsuitable.

The weight flow (W) through the intake was computed using the measured pressures obtained during traverses in the throat p and P to form p/P, and hence from the Orenda flow tables a value of $W\sqrt{T}/AP$, and therefore the ratio W/A as a function of the radius (r). Numerical integration of the area under the curve of W/A plotted against πr^2 gave the weight flow (W) in lb/sec. The results of the analysis, carried out for each throat traverse, are given in Figure 15 which shows the variation of weight flow with throat Mach number.

A flow coefficient, W (actual)/W (theoretical), was obtained by calculating a theoretical W based on a centre line pressure ratio and full flow area. For the six pressure traverses made in the throat the ratio $W(a)/W(th)$ averaged 0.985 with $\pm$ 0.5% scatter.

An additional set of measurements was made on the intake and these took the form of a series of 3 pitot-static traverses made upstream of the throat. The purpose behind these measurements was to establish how the velocity profile (distortion level) changed upstream of the throat and whether or not the intake could be shortened any appreciable amount in the axial direction. The tests were all made at approximately the throat design Mach number (0.402) and took place at the positions shown in the sketch on Figure 16. This last figure also shows the measured velocity profiles plotted on a very large scale to more clearly illustrate the flow changes which occur just upstream of the throat. From each of these four velocity profiles a distortion factor can be computed and the results plotted against distance upstream from the throat as shown in Figure 17. It is quite evident that the flow turning is not complete in this intake until the throat position is reached or slightly thereafter and consequently no shortening of the intake can be made unless the inducer leading edge can withstand some change in incidence. The position of the inducer vanes in the final design required it to handle approximately 5% flow distortion.

Another point that is of interest in intake or diffuser design is how or in what manner the area varies through the duct. Assuming a central streamline from the electrolytic tank results of Figure 5, the intake area ratio A/A_{throat} plotted against distance along the centre line is shown in Figure 18. The contraction rate appears to be very nearly linear to within a half inch or so of the throat.

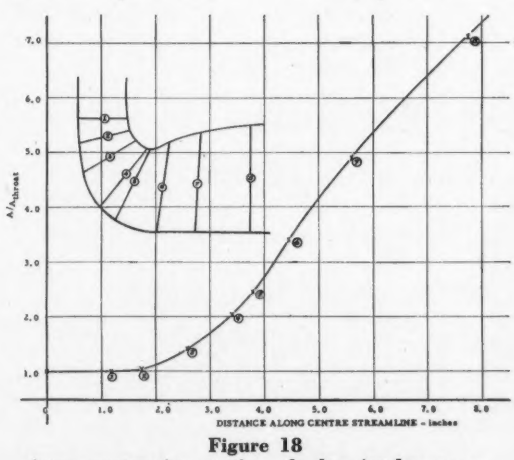


Figure 18
Area contraction ratio of the intake as a function of distance along the centre streamline taken from electrolytic tank tests

CONCLUSION

The full scale wooden model of the intake showed good aerodynamic characteristics over a range of throat Mach numbers from 0.175 to 0.417. This latter figure is just slightly over the design Mach number of 0.402. The velocity profiles measured in the throat were quite flat with an average flow distortion of $1.6 \pm 0.1\%$ over 90% of the annulus width.

The wall static pressures showed no discontinuities over the entire length of the intake. The pressure on the inner wall monotonically decreased until the throat value was reached. Because of the change in curvature the pressure on the outer wall was lowest just downstream of the point of maximum curvature, with a continuous rise taking place from this point to the throat. This means of course that a positive pressure gradient exists in the region just upstream of the throat. However, the continuous contraction that takes

place in the intake prohibits separation, at least up to the highest Mach number tested. The wall velocities plotted non-dimensionally (V/V_{throat}) gave no indication of Mach number effect and showed that V_{max} occurring at the point of minimum static pressure was very close to 1.2 V_{throat}.

Using one-dimensional flow equations and the measured pressure ratios permitted the calculation of the weight flow through the intake as 1.4 lb/sec at a throat Mach number of 0.41 with a flow coefficient of 0.985.

A series of pressure traverses upstream of the throat revealed the fact that flow distortion increases markedly in that direction. The distortion level at the proposed position of the leading edge of the inducer vanes is approximately 5%.

The electrolytic tank, the results from which were quite well substantiated by the aerodynamic tests, is shown to be extremely valuable as a design aid in the three-dimension axially symmetric flow problems.

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CANADIAN HIGH ALTITUDE RESEARCH SYMPOSIUM

To be held by the Astronautics Section

CHATEAU LAURIER
OTTAWA
20th and 21st October, 1960

NEW PROBLEM AREAS IN AIRCRAFT PROPELLER DESIGN†

by G. Rosen*

Hamilton Standard Division
United Aircraft Corporation

SUMMARY

A brief review is presented of the advances in aircraft propeller design from the trial-and-error art of the early years, of fixed pitch and ground adjustable propellers, to the precise aerodynamic and structural design of propellers for today's high performance aircraft. The trend in propeller selection from the use of off-the-shelf models to the tailoring of a specific design for each new aircraft installation is described. New problem areas being generated by the more stringent performance requirements of tomorrow's advanced aircraft are considered and some of the current research and development efforts of the propeller industry aimed at providing the required new technologies are outlined.

INTRODUCTION

In this dawning era of man's conquest of time and space, as evidenced by the advent of high-speed jet transports, sputniks, moon shots and with even more sophisticated vehicles of transportation in the offing, it may seem to be somewhat of a anachronism to be discussing aircraft propeller design problems at this time. However, examination of future commercial and military transportation requirements clearly indicates a parallel need for the less glamorous, "workhorse" type of aircraft which can efficiently transport large payloads over long distances at moderately high airspeeds. This, coupled with the obvious desirability of minimizing airport size requirements and meeting the specialized requirements for VTOL, has put an added premium on takeoff performance. In view of the propeller's inherent superiority as a low speed propulsive device, these considerations have served to refocus attention on the propeller for such future applications. However, the performance requirements for this next generation of propellers will be quite stringent and will pose some new and challenging problems to the propeller designer.

As an active member of the aircraft propeller industry through its formative years, I have been privileged to have both observed and participated in many of the major engineering developments which have brought the aircraft propeller to its present state of technological advancement. Instrumental in this progress has been an intensive program of applied research in such varied fields of engineering as materials, structures, vibrations, aerodynamics, thermodynamics, electronics, fluid mechanics and control dynamics. An appreciation of the scope and caliber of this past and continuing development effort should serve as an effective backdrop against which new design problems can be highlighted.

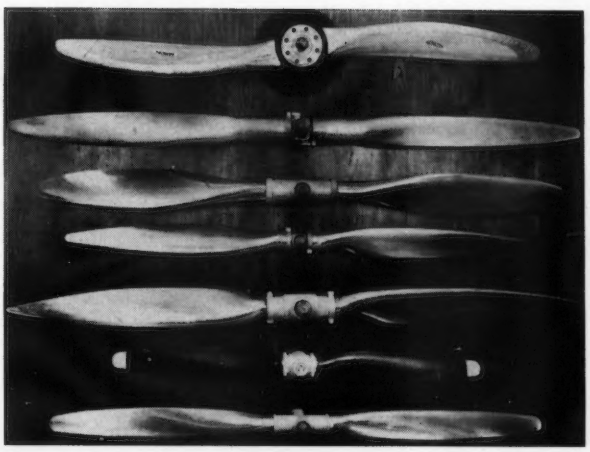

Figure 1
Early propeller types

THE EARLY YEARS

In the period prior to 1930, aircraft propellers were comparatively simple propulsive devices, fixed-pitch or ground adjustable with narrow, tapered-tip blades (Figure 1). The introduction of more durable metal blades resulted in a departure from the wide variety of blade shapes seen in the earlier wooden propeller era. Performance considerations were rather elementary. The primary concern was the selection of the proper blade size and pitch setting for best compromise of engine performance over the range of aircraft flight conditions. Accuracy of propeller performance predictions was relatively unimportant and, when required, the aerodynamic performance was approximated from the most appropriate set of the few available wind tunnel tests of propellers. Propeller structural design was rather elementary, dealing primarily with the stressing due to steady loads and bending moments. Blade fatigue strength criteria were only beginning to be developed and were still quite crude.

†Paper read at the Mid-season Meeting of the C.A.I. in Edmonton on the 20th February, 1960.
*Chief of Analysis

THE THIRTIES

During "The Thirties", the propeller industry began to take its first major technological strides. Metallurgical developments and application of refined stress analysis methods contributed to a more universal use of metal-bladed propellers. This, coupled with the pioneering of instrumentation and techniques for measuring blade vibratory stresses in flight, now gave the designer a potent tool for refinement of blade design. The introduction of variable pitch propellers was quite revolutionary, and was regarded as the "gear shift" of the airplane (Figure 2). In conjunction with engine reduction gearing, this permitted more effective engine power utilization and shifted the focus of attention to refinement of aerodynamic design of the blades. The increasing availability of propeller wind tunnel tests now provided a basis for development of generalized empirical methods of performance analysis from which the effects of propeller geometry on performance could be studied.

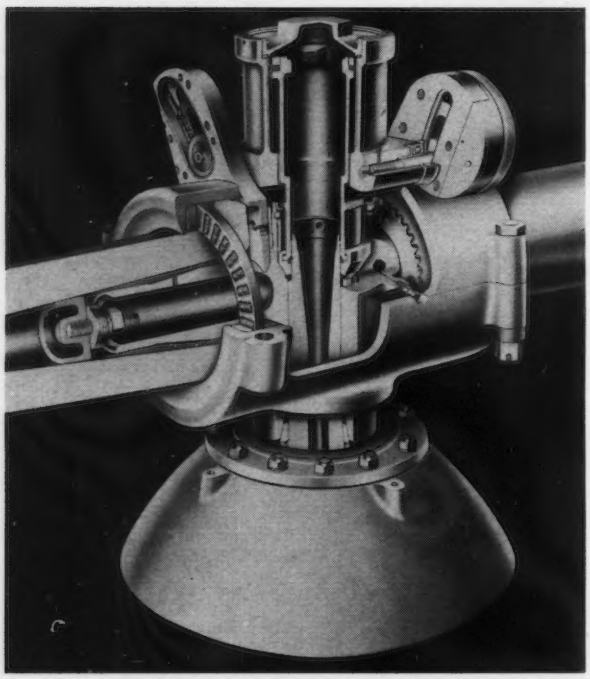

Figure 2
Cutaway of variable pitch propeller

WORLD WAR II PERIOD

The advent of World War II with its rapid advances in aircraft speed, size and engine power called for parallel progress in the field of propeller performance. Effort was directed toward the development of more sophisticated methods of aerodynamic design, culminating in the so-called "Strip Analysis Method" – a refined blade element form of calculation based on the propeller vortex theory derived by Prandtl and Glauert and perfected by Goldstein and Lock. Along with this came the application of more efficient airfoil shapes such as the low-drag, laminar flow types with improved L/D and critical Mach number characteristics. This represented a major breakthrough in the propeller aerodynamics field and contributed significantly to the aircraft performance advances of this period. A wider variety of blade shapes for different classes of aircraft were in evidence and there was a definite trend toward wide, multi-bladed propellers to minimize diameter requirements (Figure 3).

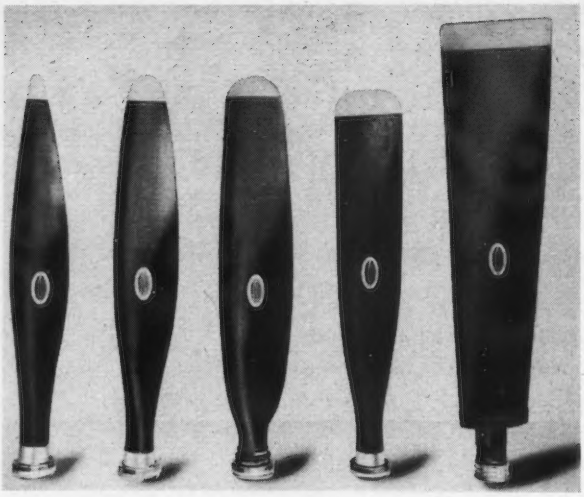

Figure 3
Trend toward wide, square-tipped blades

In addition to the aerodynamic refinements, the propeller was called upon to provide new mechanical features to cope with the operational requirements of the more advanced aircraft. Blade feathering was introduced as a means of stopping rotation of a malfunctioning engine to prevent destructive failure and to simultaneously reduce propeller drag. Blade reversing was developed to supplement wheel brakes in reducing landing roll of the low drag aircraft (Figure 4). Blade de-icing provisions – initially by fluid depressants and ultimately by electrically heated elements – were incorporated to permit all weather flying. The aircraft

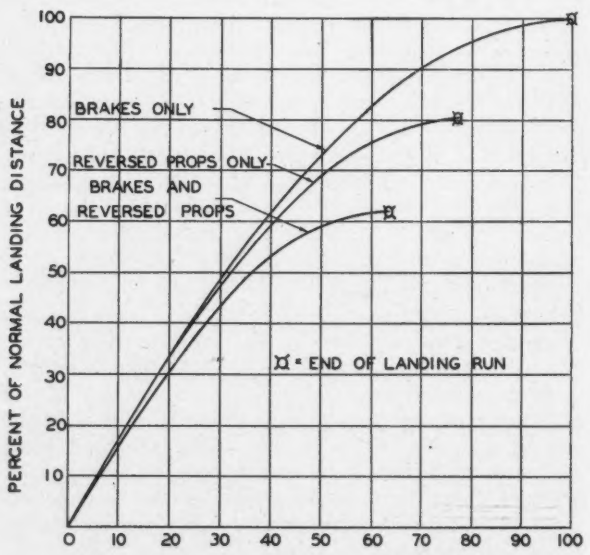

Figure 4
Comparative test results of landing characteristics of reversing propellers

propeller was in process of maturing into an advanced mechanical propulsion system of the same order of complexity as the powerplant, requiring the perfection of new skills for successful design and development (Figure 5).

POST-WAR PERIOD

The aircraft advances spurred by military wartime requirements gave birth to a new generation of high performance commercial transports in the post-war period. These larger, faster aircraft, no longer space-limited in their load carrying capacity and with greater range capabilities, put a premium on high efficiency at minimum specific weight of the propulsion system. Accordingly, there was a marked trend from the previous practice of selecting off-the-shelf propeller models to one of specifically tailoring optimum propeller designs for each new installation. This required the perfection of techniques for designing blades of optimum aerodynamic performance and saw the adoption of the Strip Analysis Method as a universal design procedure by the propeller industry. Further streamlining of its complex computing process and ultimately programming it for high-speed, digital computers have materially facilitated its effectiveness as a design tool. Single point efficiency calculations, which previously required 2-3 hours by hand, can now be machine-computed at the rate of 10 per minute. This increase in speed of computation is reflected in more detailed aerodynamic tailoring of propeller blade shapes to the specific performance requirements of each installation.

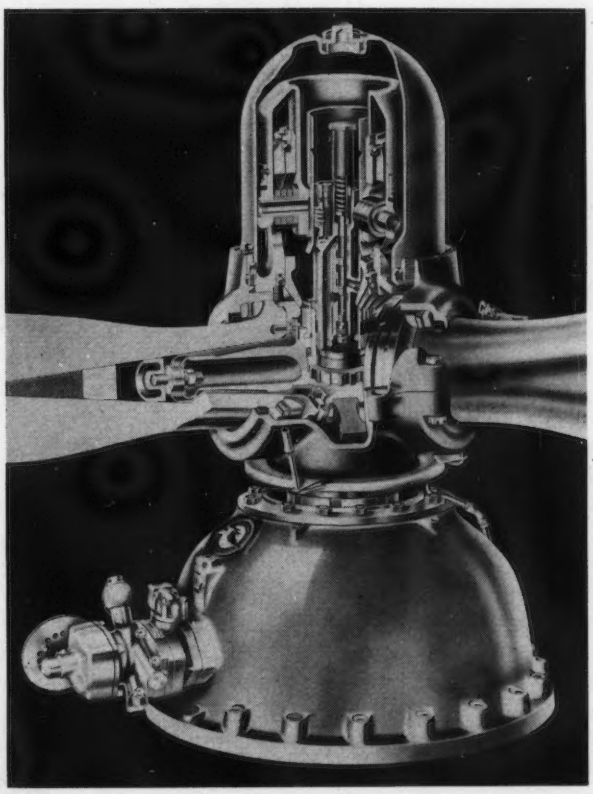

Figure 5
Cutaway of hydromatic propeller

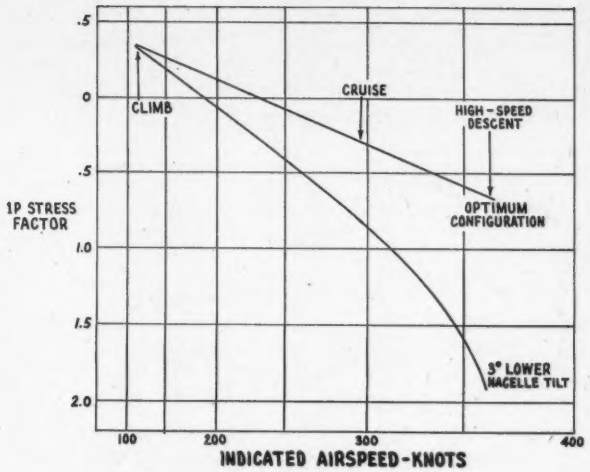

Figure 6
Typical 1P blade stress diagram

The trend toward higher speed aircraft and larger diameter propellers resulted in increasing magnitude of asymmetric air loading on propeller blades in the extreme flight conditions of climb and high speed descent. This coupled with the requirement for thinner blades for minimization of compressibility losses at these higher flight speeds has introduced the so-called "1P" blade stressing as one of the major blade structural design problems. At the high speed end of the flight spectrum, oscillatory blade loadings and resulting stresses are quite sensitive to airflow direction into the propeller, as illustrated by the example of Figure 6. In this case, a beef-up of the propeller blades to provide the same stress reduction as the 3° change in nacelle tilt might have cost a propeller weight increase approaching 10%. The increasing prevalency of this problem has been reflected, first in greater cooperative effort between propeller and aircraft designer to minimize the excitation, and then the application of advanced methods of analysis in the structural tailoring of the blade to safe 1P stress levels at minimum weight. Obviously each aircraft installation is unique in its propeller performance requirements relative to the degree of structural problem imposed. Thus today's aircraft evidence a wide variety of blade shapes, each representing the best compromise between performance and weight without sacrifice of structural integrity.

Paralleling the aircraft performance advances, there has been equal emphasis on improved passenger and crew comfort. One of the major efforts has been the minimization of interior noise levels and vibration. In this area, the propeller has made a significant contribution by first developing an effective propeller synchronizing system for multi-engine aircraft and, more recently, providing the additional feature of synchrophasing. Whereas the synchronizer, by holding the relative speed of all engines to within a fraction of 1 rpm, completely eliminated the noise due to propeller beats, there still remained a source of cabin noise resulting from pressure wave amplification at certain phasing between the several propellers. A solution was found in the recently perfected propeller synchrophaser which can hold a predetermined optimum

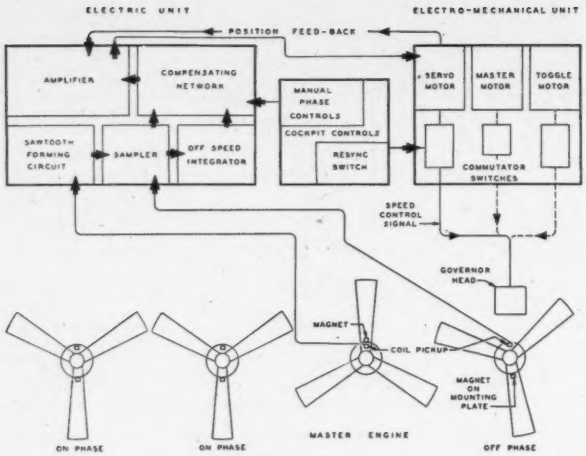

Figure 7
Block diagram of propeller synchrophaser

phase relation within ± 10° (Figure 7). The combination of synchronizing and synchrophasing on several four-engine transports has demonstrated cabin noise reductions of the order of 10 db. To achieve this degree of control on speed synchronization and blade position phasing involved a pioneering effort, on the part of the propeller industry, in developing electronic control components and circuitry of advanced precision, reliability and durability.

The need for improved aerodynamic design criteria for high speed propellers was recognized early in the post-war period. This instigated an intensive research effort involving both analytical and wind tunnel investigations (Figures 8 and 9). Such principles as low aspect ratio and sweepback which had proven effective on high speed wings were appraised. However, their effectiveness when applied to a propeller blade was considerably

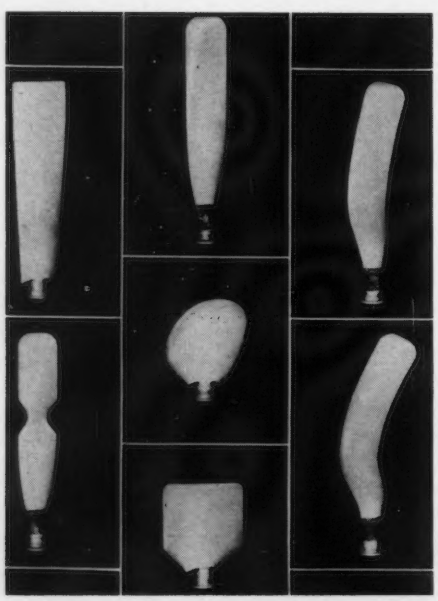

Figure 8
Series of high speed wind tunnel models

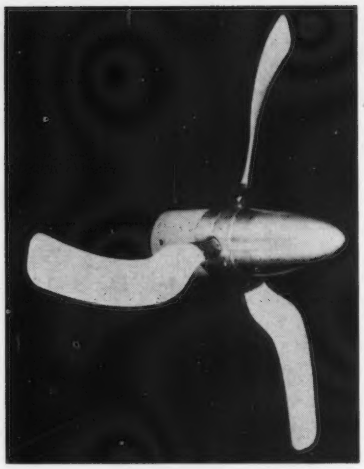

Figure 9
Wind tunnel model of sweptback propeller

limited by the attendant blade structural problems. For equal degree of structural problem, the most effective means for improving propeller performance at high speeds was found to be reduction of blade thickness ratios. Figure 10 illustrates the magnitude of improvement achieved by cutting blade thickness ratios approximately 50%. This research effort also confirmed the concept of the ultra-thin supersonic propeller for maintaining high efficiency levels through the transonic flight range.

This demand for thinner blades called for radical advances in blade structural design. Although this effort contributed to a degree of refinement of the solid aluminum blade in the direction of wider, thinner blades

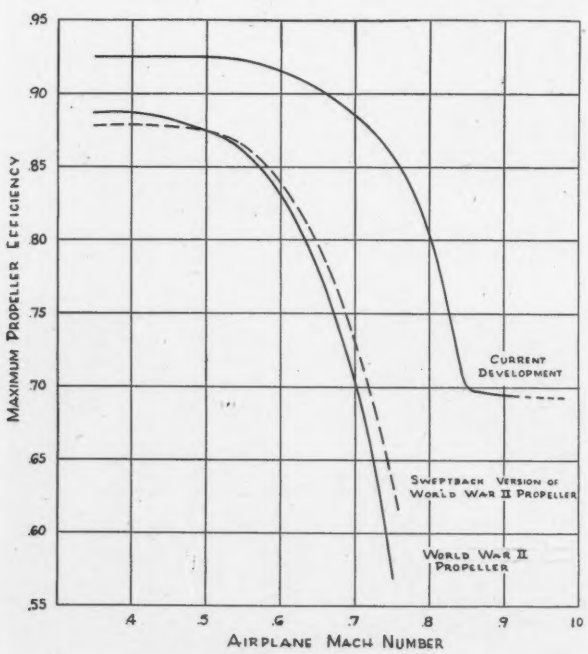

Figure 10
Summary of high speed propeller wind tunnel tests

(Figure 11), the more stringent structural requirements, particularly in the larger diameters, led to the development of hollow steel blade structures (Figure 12). These introduced a whole new order of engineering and fabricating effort to produce successful blades. Some of the major problems were the development of techniques for high strength bonding of metal to metal and metal to plastics, control of blade contours, fatigue strength criteria, erosion and corrosion protection, process controls, and specialized tooling. Hollow steel blades have seen installation on commercial and military aircraft with accumulated flight time totalling in the millions of hours (Figure 13).

The primary purpose of the foregoing review of the aircraft propeller history was two-fold: to describe the current state of the art in propeller development, and to depict the broad technological background that is available for application to the solution of new problems. I would now like to discuss some of these new problems facing the propeller designer, and the direction of effort aimed at their solution.

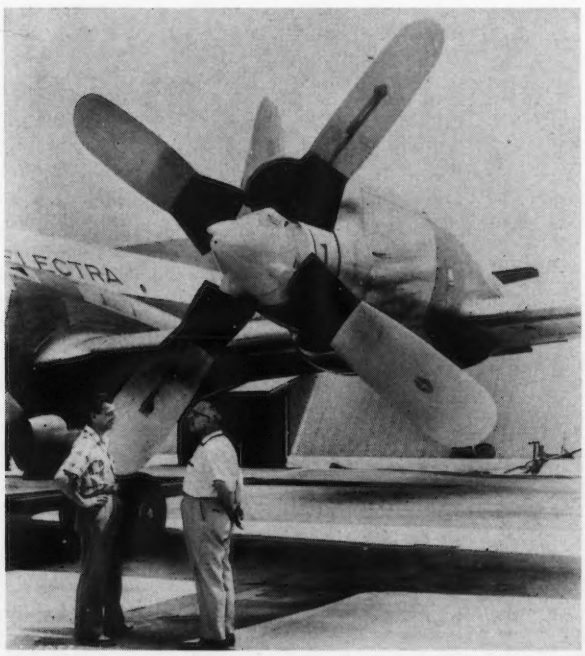

Figure 11
Wide, thin aluminum blades on Lockheed Electra

PROPELLERS FOR TOMORROW'S AIRCRAFT

The advent of a new generation of turboprop engines of advanced specific horsepower ratings has encouraged the development of special purpose aircraft having attractive performance capabilities. These fall into several categories, of which some of the more important are:

(a) Long duration aircraft (e.g. AEW and ASW).
(b) High-speed, long-range transports.
(c) High-speed, ground support aircraft.
(d) STOL/VTOL aircraft.

Although these obviously run a wide gamut of configuration and mission, they have a common characteristic of being performance critical at more than one operating condition, thus posing stringent propeller performance requirements. In attempting to meet these requirements with propellers of conventional design, it becomes quite apparent that severe compromises between takeoff performance, level flight performance, propeller diameter and propeller weight are unavoidable.

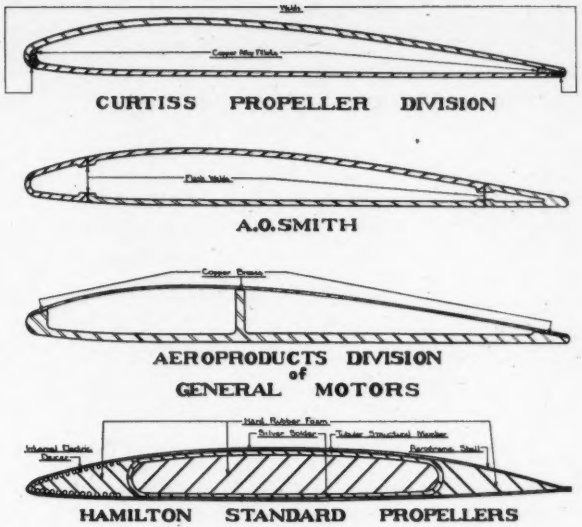

Figure 12
Types of hollow steel blade structure

Various means have been considered for alleviating some of these compromises, but they are generally characterized by the introduction of compensating penalties. For example, the consideration of two-speed reduction gearing, by permitting the selection of optimum propeller speeds for both cruise and takeoff, is quite attractive from the performance standpoint. However, the increase in weight and mechanical complexity involved in the provision of two-speed gearing may well offset the performance gains. Similarly, other considerations such as blades with boundary layer control, tip rockets, jet flaps etc each introduce offsetting penalties in the form of weight increase and structural complexity. Moreover, requirements for both actuation and constant

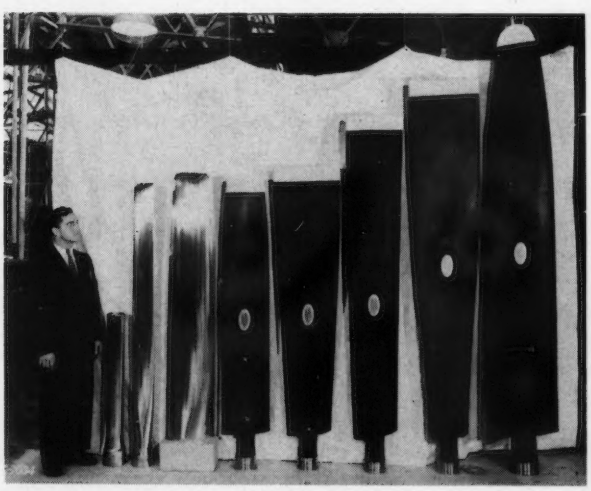

Figure 13
Typical hollow steel blades

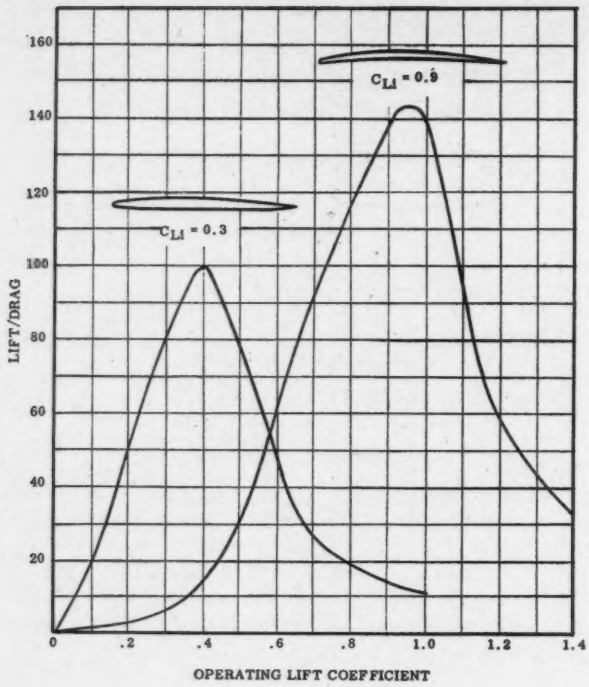

Figure 14
Effect of camber on performance of a typical airfoil

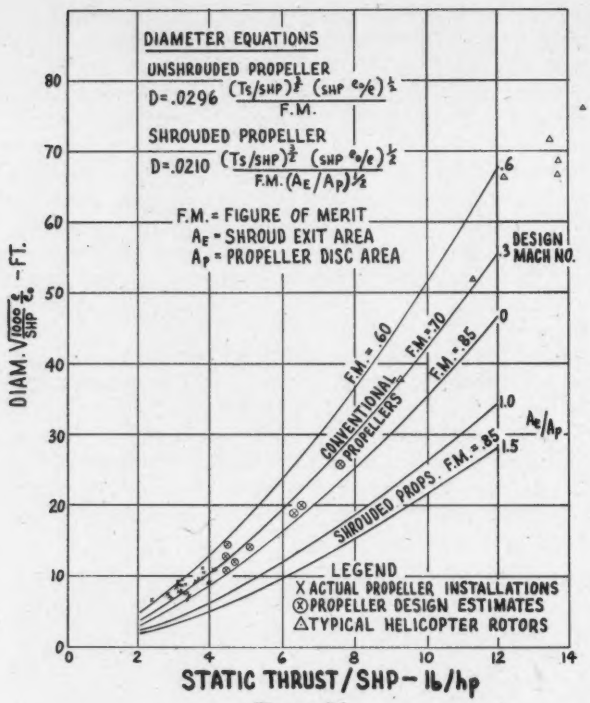

Figure 16
Propeller diameter trends

energization of a supplementary control system throughout the critical takeoff and landing regimes would seriously prejudice system reliability.

One means of improving takeoff and climb performance, which is attractive due to the fact that it does not introduce a weight penalty, is the incorporation of high-cambered airfoils in the blade. At the high lift coefficients where the blade airfoils operate during takeoff and climb, increase in camber provides improved airfoil L/D ratios and consequent improved propeller performance. Under cruise operation, however, the blade airfoils are at much reduced lift coefficients where the L/D of the high cambered airfoil deteriorates rapidly. Thus although takeoff and climb performance benefits can be derived from the use of high cambered blades, cruise performance penalties of varying degree are unavoidable (Figure 14).

Two potentially attractive solutions to this problem are indicated:

(a) A new family of airfoils which can maintain high L/D over a wide range of lift coefficients and up to the transonic Mach No. range where propeller sections operate.

(b) An effective means of varying blade camber without undue weight or complexity.

Investigations are currently in process in both of these areas with some promising indications to date.

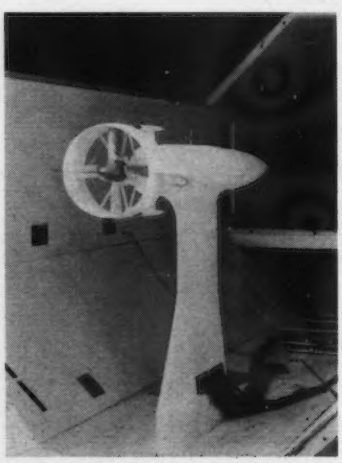

Figure 15
Shrouded propeller model in wind tunnel

Operation of a propeller in a shroud has also shown potential takeoff performance benefits and is receiving serious consideration for VTOL application (Figure 15). However, the limited available test data on shrouded propellers indicate rapid deterioration of performance at moderate flight speeds due to the build-up of shroud drag. This, coupled with the obvious weight penalty of the shroud, may become prohibitive unless it can be shown that the shroud can produce a compensating amount of lift during cruise. Several research programs on shrouded propellers are being actively pursued to find the answers to these questions.

In general, however, STOL/VTOL aircraft with requirements for very high values of static thrust/shp will require relatively large diameter propellers as illustrated in Figure 16. This diameter trend is established by the fundamental equations which show that, for given engine power and air density, the diameter increases as the three-halves power of the T_s/shp ratio and inversely as the figure of merit. Figure of merit is defined as the ratio of actual power to ideal power required to produce static thrust and is used in lieu of efficiency which, of course, is meaningless at zero airspeed. Its magnitude is a function of propeller tip speed, solidity and camber with an upper limit of approximately FM = 0.85. Since tip speed, solidity and camber must all be reduced to

maintain good cruise efficiencies with increasing flight speed, the attendant lowering of the figure of merit accounts for the trend of larger diameter with higher design Mach No. It is interesting to note that helicopter rotors fall within the same range of figure of merit as that of aircraft propellers.

As a typical VTOL example, a requirement of 5.0 lb of static thrust/shp with a 4000 shp engine on a moderate speed aircraft would require a conventional propeller with a diameter of approximately 30 ft for good cruise performance. Even an optimum static thrust propeller with no regard for cruise performance would be 25 ft in diameter, and a shrouded propeller would cut the diameter requirement to only about 17 ft. Compared with the conventional 13.5 ft diameter propeller used on the Lockheed Electra with this size of engine, it is obvious that we are confronted with a completely new order of propeller size requirements.

Figure 17 presents an extrapolation of conventional propeller specific weights to cover this range of large-diameter, high-thrust propellers. Although no attempt was made to define shrouded propeller weights, it is believed that these same curves may crudely approximate the total weight of the shrouded propeller, despite its much reduced diameter. The extrapolation is based on a number of propeller design studies for typical VTOL requirements and assumes no refinements over current hub and blade construction. Thus Figure 17 may be presumed to provide a most conservative weight forecast for STOL/VTOL propellers but, even on this basis, the curve slopes have not reached the break-even point where weight increase would completely offset thrust gain. However, since every pound of propeller weight reduction means a pound increase in useful load on a VTOL airplane, there is a pointed need for the development of new concepts of lightweight propeller construction.

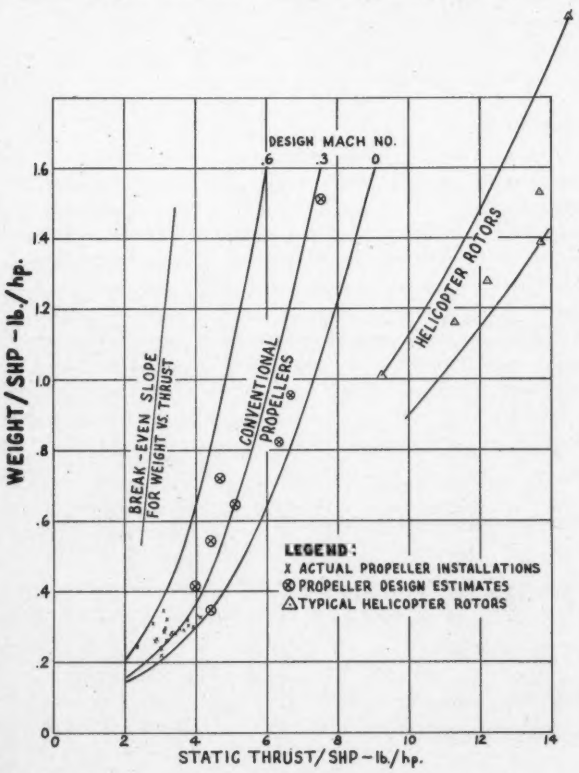

Figure 17
Weight trends for propellers of conventional construction

Figure 18
Large diameter propeller on engine test stand

Fortunately, the reduced disc loadings and tip speeds, characteristic of these larger diameter propellers, offer a definite potential for lighter hub and blade structures (Figure 18). Some typical current considerations are: the use of new materials, such as titanium or high strength plastics; the design of cellular blade structures; blade articulation, etc. Such developments, if successful, should result in weight reductions of the large diameter, lightly loaded propellers to a more attractive level perhaps closely approaching that of the helicopter rotors.

Another potential source of weight saving is by refinement of the means of attachment of the propeller to the engine. Large propellers impose correspondingly large side loads and bending moments on the engine shaft and its bearings, to the point where prohibitive weight penalties would result with the conventional splined shaft type of propeller mounting. A new type of mounting, called "nose-mount", has been developed whereby all propeller loads except torque are transmitted to a large diameter bolt circle on the engine nose, and the propeller is driven by a simple quill shaft which merely transmits torque. Although this involves an increase in propeller weight over the conventional spline-mounted type, there is a larger weight reduction on the engine. Nose-mount propellers have been built in diameters up to 20 ft with an equivalent weight saving in terms of propeller weight of approximately 10%.

A recent outgrowth of the nose-mount development is the consideration of incorporating the reduction gear-

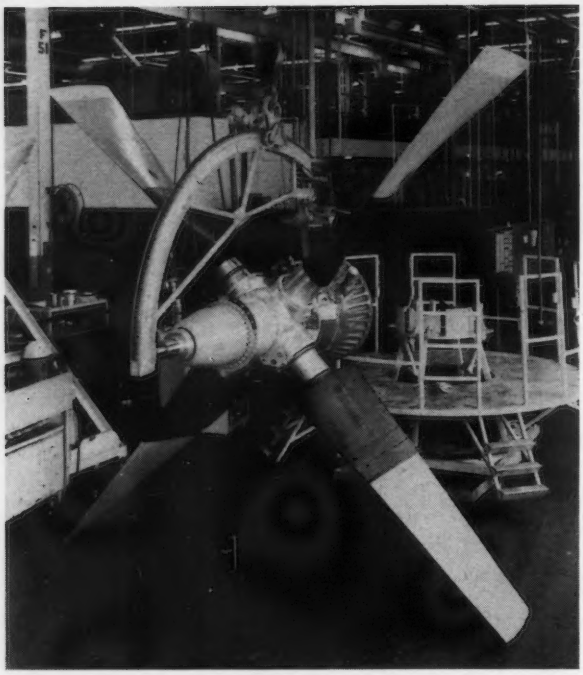

Figure 19
Nose-mount type propeller

ing in the propeller hub. The nose-mount type housing on the propeller can also serve to provide a considerable portion of the housing required for the gearing. This avoids duplication of housing hardware on propeller and engine, and is particularly attractive in the case of propellers mounted remotely from the engine. Design estimates on several engine applications have indicated an additional equivalent weight saving of approximately 20%. Thus, the total equivalent weight saving of nose-mount with integral gear box may approach a respectable 30%. Programs for development of this type of propeller are currently under consideration (Figure 19).

Tomorrow's advanced turboprop aircraft will also require more sophisticated propeller control systems. Some of these features have already been developed and are in operation on such aircraft as the Electra and C-130B. Some of these are:

(a) NTS – Automatic negative thrust control to limit propeller negative thrust to a safe level in the event of engine failure.

(b) Beta control – direct blade angle adjustment for faster thrust control in ground manoeuvering.

(c) Lock pitch – automatic locking blade angle to prevent movement of blades toward low pitch and consequent over-speeding on loss of propeller oil pressure.

For turboprop installation, the propeller control system must be tailored for, and developed in conjunction with, the particular engine control system. The requirement for high rate of pitch change and high degree of speed sensitivity has necessitated the application of the most advanced servo-mechanism principles to provide fully compatible systems. The functional analysis of these systems becomes quite complex and has required the application of analog computers to supplement computational studies.

Obviously, the most complex control systems will be required in the case of VTOL aircraft, due to their major dependency on the propeller as a primary source of aircraft control forces during takeoff, hover, landing and transition. One of the requirements will be a precise means of differential thrust control between the several propellers using conventional cockpit actuation. This system would need to be phased out during transition flight as the conventional aircraft control surfaces, using the same cockpit actuation, become effective. The best method of controlling blade pitch may vary over the different flight regimes and require switch-over from one to another during transition. Faster response characteristics and added safety features will undoubtedly be needed to insure against sudden, disastrous and unbalanced forces on the aircraft. These are some of the fundamental problems currently under investigation in order to develop adequate control design criteria for tomorrow's aircraft.

CONCLUSION

In summary, I have endeavoured to outline some of the typical problems now confronting the propeller industry against the backdrop of its past extensive experience. Admittedly, some of these appear quite difficult and will involve the development of new technologies. However, having faced up to equally stringent development requirements in the past and arrived at successful solutions, we are looking forward to the challenge of these new problems. We feel that propellers are here to stay and intend to apply our vast technical background to insure that the right propeller will be available for each new aircraft installation.

JOINT IAS/CAI MEETING

QUEEN ELIZABETH HOTEL
MONTREAL

17th and 18th October, 1960

TECHNICAL FORUM

A Two-Distribution Interpretation of Fatigue S-N Data†

by S. R. SWANSON*

Institute of Aerophysics, University of Toronto

SUMMARY

The statistical behaviour of single-level constant-amplitude fatigue endurances has been investigated using 2024-T4 aluminium alloy specimens under axial loading[a]. The pattern of behaviour at the 'knee' of the S-N curve was discovered to be consistent with an hypothesized rise and decay, respectively, of two endurance distributions, each representing the action of a separate fatigue mechanism. The behaviour of these distributions is discussed, statistical evidence is offered for their existence and behaviour and, finally, a few notes on the implications of this approach form the conclusion. The main aspect of this treatment is that the knee of the S-N curve is not simply an area of gradual change in dispersion and shape of a single underlying endurance distribution, but a region where two linear families of endurance distribution cross each other, or overlap. If this two-distribution approach is found to be valid, a reassessment of design criteria based on low probabilities of fatigue failure in this region will be required.

INTRODUCTION

As a preliminary step in a large program to study cumulative damage in fatigue, it was necessary to make a statistical evaluation of the single-level S-N relation. At stress amplitudes (S) above the 'knee' of the S-N curve (intermediate stresses) the test data were well represented by the single symmetrical log-normal distribution. However, as S was lowered, the data departed from linearity when plotted on log-normal probability paper.

At first, an attempt was made to fit these data to the (skew) extreme-value distribution. While a reasonable fit was obtained, the method appeared to yield little fundamental insight into the action of fatigue at the knee of the curve.

Since the distribution of ranked test results on log-normal probability paper deviated in a manner vaguely like that which one would obtain if a separate distribution were to intrude upon the first (unsuspected by the analyst) and finally become predominant, this line of reasoning was pursued. By grouping the data into the two distributions suggested from the shapes of the curves of ranked data (Figure 1) a logical pattern developed (Figure 2).

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*Research Assistant (on leave of absence from The De Havilland Aircraft of Canada Limited)

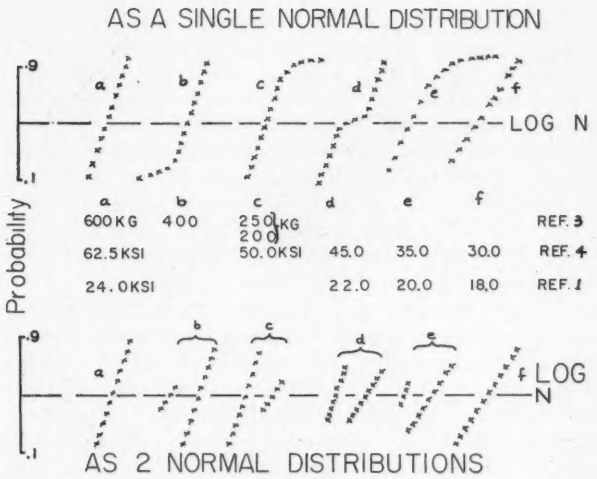


Figure 1
Comparison of interpretations of ranked log-endurances

The distributions usually exhibiting the smaller standard deviations (steeper slope in Figure 1) were found to be the logical linear continuation of the intermediate stress distributions. These are called Short Term Fatigue, STF. The distributions with the larger standard deviations seemed to indicate the emergence of the line of the single distributions characteristic of stress levels well

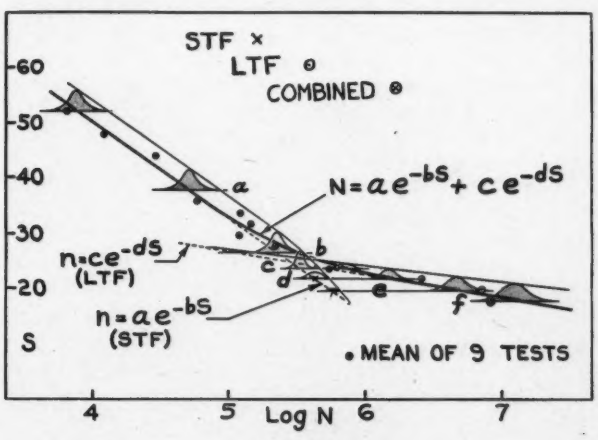


Figure 2
A two-distribution interpretation of results of Reference 1 (resulting behaviour with author's results)

below the knee of the S-N curve. These distributions are called Long Term Fatigue, LTF.

DISCUSSION

Throughout the fatigue literature, the S-log N relation has been treated in a monolithic fashion at low and intermediate stress levels, with a single exponential expression being used to fit the results. In contrast, the two-distribution interpretation was used with the data of Reference 1, and a least squares exponential regression was carried out with the aid of an IBM 650 Computer on the 15 sample means, using the expression

$$N = a e^{-bS} + c e^{-dS}$$

where N are the cycles to failure, S is the stress amplitude, and *a*, *b*, *c*, *d* curve-fitting constants obtained by iteration to a Least Squares minimum. The author is greatly indebted to Dr. B. Worsley of the University of Toronto Computation Centre and to Dr. L. Lax for generous assistance in this phase of the work. The program, developed for the field of medicine, is described in Reference 2.

The resulting S-log N curve was not only an excellent fit of the test data over a greatly enlarged range of stress amplitude, but it was possible to identify the first term $a e^{-bS}$ as passing through the STF means and the intermediate stress means, while the second term $c e^{-dS}$ was representative of the LTF and low stress means.

While the data used by the author involved the testing of only 9 specimens at each of 15 levels of stress amplitude[1], the test results of References 3 and 4 have been similarly re-examined by the author, since Figure 2 of Reference 4 and Table 3 of Reference 3 represent the relevant region with sample sizes of approximately 20 and 100 specimens, respectively. These data give striking confirmation of this behaviour (see Figure 3 for typical distribution shapes). The increase in sample size (especially for ± 40,000 and ± 35,000 in Reference 4) allows one to suspect that both the LTF and STF distributions appear to follow a log-normal probability of failure. Also it is apparent that this behaviour is unaffected qualitatively by the type of loading, the mean stress or the presence of notches. At present these observations appear limited to materials with no well-defined endurance limit. The corresponding behaviour with stress amplitude during the transition from one distribution to the other is shown for References 3 and 4 in Figure 4.

An interesting result of this approach is that it provides a logical explanation for the 6 test results rejected by Weibull (Figure 4 in Reference 3). When plotted log-normally as a second component distribution, the standard deviation was found to be greater than that of the main distribution while the mean life was less (Figure 3). It thus appears that the LTF line of distributions can extend across the STF line (b in Figure 2) and yield a small LTF distribution *preceding* the STF or intermediate stress distribution. In general, however, the distributions seem to fade rapidly and the STF and LTF lines terminate within the transition region. Possibly a great deal of the usual jaggedness of the line joining the endurance means near the knee of the curve would be removed if a metallurgical and/or statistical study were to separate single endurances arising from the non-zero probability of second-distribution failures.

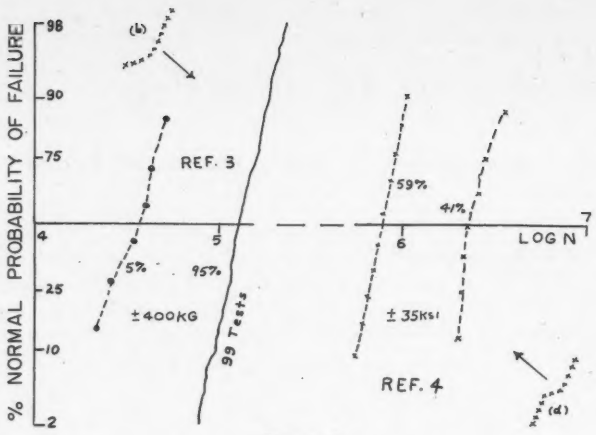


Figure 3

Typical results of replotting data (examples of this treatment with large-sample tests)

In the Figures, the percentages indicate the division of the test results.

CONCLUSION

It is possible of course, to obtain component distributions as the result of inaccuracies in amplitude settings and "inherent scatter". However the standard deviations are usually quite similar, and the distributions overlap within the sample range of probabilities. In the separation of the data of References 1, 3, and 4 no overlap occurred, and there was an obvious difference (by a factor of about 3 in Reference 1) in the standard deviations of the component distributions. Also the means (e.g. at 22 ksi in Reference 1) were separated by as much as one cycle (or more) of log N requiring an amplitude error far too great to be resolved by inaccuracies. Also inaccuracies in settings would result in a random arrangement of distributions rather than the orderly continuation of straight line segments observed here. Nevertheless, the sequence of events in the transition from one distribution to another occurs in an extremely small interval of stress amplitude (6 ksi in Reference 1).

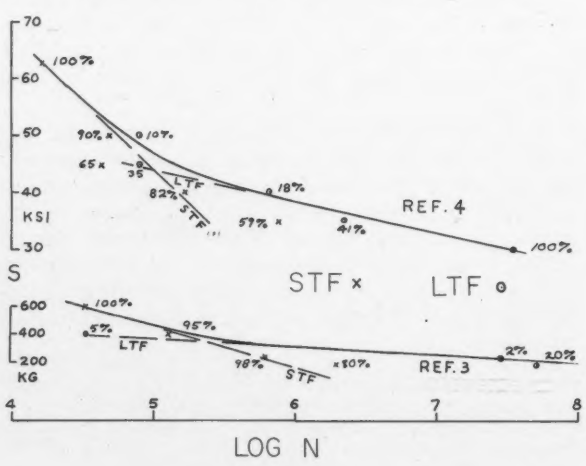


Figure 4

Two-distribution interpretation of results (resulting behaviour with large-sample data)

Recent studies in England by Porter (Reference 5), not yet available to the author, describe the existence of two fundamental fatigue mechanisms at the metallurgical level, and mention their dual existence at the knee of the S-N curve. Such work appears promising as confirmatory evidence. Perhaps the STF mechanism is one of crack propagation "on many fronts" while the LTF mechanism is essentially one of unilateral crack propagation.

The present approach also appears to confirm the existence of fatigue crack growth mechanisms which yield a linear relation between S and log N at all stress levels. The coupling of two mechanisms of this type can be seen, in this manner, to explain the complete fatigue behaviour, including the 'knee', of the S-N curve at intermediate and low stress amplitudes.

If the two-distribution approach is found to be valid, a reassessment of design criteria which are based on low probabilities of fatigue failure will be required. The low probabilities of failure would then be calculated from a combination of

a) The probability of occurrence of failures in the first distribution encountered relative to those of the second, and

b) The probability of failure within the first distribution.

REFERENCES

(1) Swanson, S. R. — *Systematic Axial-Load Fatigue Tests Using Unnotched Aluminum Alloy 2024-T4 Extruded Bar Specimens*, UTIA Technical Note No. 35.

(2) Lax, Dr. L. C., Reid, Prof. D. B. W., and Worsley, Dr. B. H. — *Error Estimation of Fitted Exponential Functions and Transfer Rates of Plasma Constituents Determined by the IBM 650 Computer*, Proceedings of the 2nd Conference of the Computing and Data Processing Society of Canada, June 6, 1960.

(3) Weibull, W. — *Static Strength and Fatigue Properties of Threaded Bolts*, Report 59, The Aeronautical Research Institute of Sweden, 1955.

(4) Sinclair, G. M., and Dolan, T. J. — *Effect of Stress Amplitude on Statistical Variability in Fatigue Life of 75S-T6 Aluminum Alloy*, Transactions of the ASME, Vol. 75, p 867, July, 1953.

(5) Research Report No. 1, Northampton College of Advanced Technology, London, England, December, 1959.

Design of Ground Effect Vehicles†

by Dr. W. R. Bertelsen*

Bertelsen Manufacturing Company, Inc.

After several years of experience in operating full scale ground effect vehicles over all kinds of terrain under a wide variety of conditions, certain design requirements have become apparent.

Of basic importance to the success of any given ground effect vehicle are simplicity of design, efficiency, stability, controllability, and several auxiliary features such as flotation and dust, spray and snow deflection.

SIMPLICITY

The irreducibly simplest design of the ground effect vehicle is that of single engine and single fan. Failure liability, first cost and maintenance are all minimized in the single motor fan vehicle. For the small machine as contrasted to large ocean going GEV, further elaboration of mechanism is unnecessary.

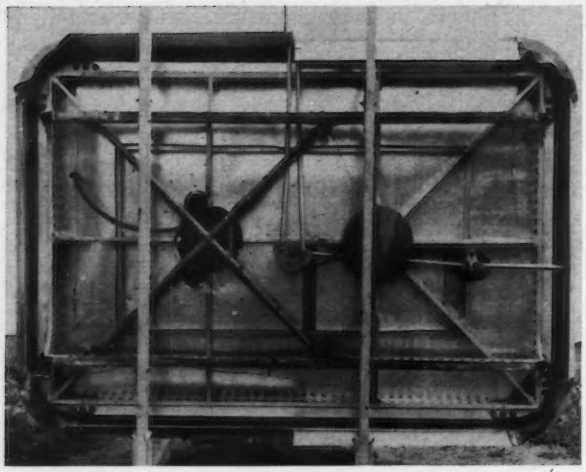
EFFICIENCY

Maximum efficiency is attained when the greatest possible thrust augmentation is obtained per horse power. Very early in ground effect design these machines were considered to be properly almost pure pressure operated and very thin jets were recommended. The mass flow and thrust, the very thing which was to be "augmented" by ground effect, was cut down. An efficient GEV must have a large mass flow of air to obtain the largest possible reaction lift further augmented by pressure beneath the base. Large mass flow is most efficiently obtained through a large multiblade fan turning slowly and, to avoid constriction and back pressure, the jet area should be large.

Aeromobile GEV

†Paper presented at the April, 1960, meeting of the Ottawa Branch of the C.A.I.

*President



An underside view of the Aeromobile GEV. Note the linkage and cable arrangement for the six jet control flaps.

STABILITY

Stability in pitch and roll in the GEV becomes an acute problem when altitude rises over 10% of the base diameter. The single plenum chamber machine is unstable in pitch and roll in this region and higher. The peripheral jet GEV can be stabilized by large mass flow through its periphery. Reaction produces an upward force at the widest possible base and is stabilizing. The peripheral jet GEV with thin jets, and consequently low thrust, (using motor fans rather than jet engines) is relatively unstable because the major lift force (pressure) is exerted through the geometric center of the base. The thin jet, low reaction thrust peripheral jet machine teeters on a central lift vector with its center of gravity above the pivot point.

The plenum chamber and the peripheral jet machines can both be stabilized by compartmentalization of the base. By having four plenum chambers, or four center bodies surrounded by jets, the vehicle stands on four legs instead of one.

The most critical area is roll stability in the GEV which is longer than its width. Unstable rectangular or oval machines tend to lie on one side or the other.

Any negative angle put on the peripheral jet is destabilizing in the small machine. Inward deflection of the jet is also critical in altitude and not sufficiently rewarding of increase in altitude or weight lifting to warrant consideration. The most efficient and stable design is with large area vertical jets with high volume passing straight through.

Stability in yaw in the GEV can be achieved by a vertical tail surface, but the introduction of weather cocking and the necessity of crabbing in cross winds rule out its use. A single yaw axis auto-pilot is a means of achieving yaw stability, but the best means for personal vehicles would be to operate them in shallow grooves. Existing highways can be enlarged in capacity, at very low cost, by grading the grooves into the shoulder and ditch and resowing to grass for GEV. Groove travel will accomplish stabilization of the vehicle in yaw, cheapen highway construction, and make possible, ultimately, the complete automation of personal transportation.

Lack of inherent stability in yaw, is not, however, a serious fault if good controllability is obtained. In many operational conditions sideways or diagonal travel is advantageous.

CONTROLLABILITY

The GEV, unlike the aircraft, is forced to meet the rigors of the terrain on its own "ground". The fixed wing craft or helicopter operator will select a proper runway with correct wind direction and climb to altitude on his own terms and then tackle a mountain or hill. However, the frictionlessness of the operating medium, although good on level surface, is detrimental to the GEV on hills because inexorable gravity forces the machine to the lowest possible point.

It is, of course, possible to add thrust from auxiliary sources such as propellers, air bleed jets, ducted fans, rockets etc to force the machine uphill and to brake them against toboganning downhill. In addition to the weight, cost and fuel cost of these auxiliaries, they have the disadvantage of not acting through the center of gravity in all directions and thus causing extraneous roll, pitch or yaw motions.

It is possible to make the GEV rise vertically like a VTOL up a sheer cliff with the addition of sufficient power and with disregard of the efficiency of the unmodified base out of ground effect. It should be possible, therefore, to force the machine up an inclined plane with its principal lift source by tilting it uphill. The additional force required to move it uphill would be from zero to full gross weight as the angle of the plane rises from zero to 90°.

The proper place for additional forces for grade climbing would seem to be through the main lifting base where existing controls can assure moments of force acting in 360° directly through the center of gravity without unwanted torque. By installing sufficient power in the single motor fan unit, the cheapest, simplest and most controllable propulsive force can be obtained.

Consider the operation of the machine in strong cross winds or in negotiation of side hills. In cross winds a continuous extra power bleed must be done by the non-tilting GEV merely to maintain the hovering or travelling machine steady relative to the earth or its path.

GEV shown here in flight

On side hills, the machine which cannot tilt opposite the hill will require large amounts of power just to maintain it on the hillside and more to lift and propel it.

Control of tilt is important for several other reasons aside from obtaining propulsion and control through the main power source and lifting base. Reverse thrust for braking is also obtained by rearing up the nose of the craft. Very powerful and fully controlled braking force is obtained.

Trim of eccentric loads by tilt control will prevent listing and consequent motion in the direction of list. A listing machine requires power bleed in some form to counter the tendency to drift.

The ability of a GEV to take a tight turn depends on its production of an inwardly directed radial force to prevent tangential motion. Tilting is the best means to produce this force and is the means that aircraft have used since the Kitty Hawk biplane. Control of pitch, roll and yaw is as essential to the GEV as it is to any other aircraft.

OTHER DESIGN REQUIREMENTS

Inherent flotation to enable safe travel over water and allow resting on water is absolutely necessary for all GEV.

Dust, spray and snow deflectors or "fenders" must be permanently designed into these craft because they and their occupants tend to get dirt, water or snow thrown onto them in large quantities. Water runs off, but dust and snow build up and tend to load down the machine. The deflectors may be simple plane surfaces some distance above the bottom of the vehicle and extending out about the same distance horizontally.

Safety harness for all passengers must be provided because of rapid accelerations possible in operating these craft.

The GEV is at once the simplest possible land vehicle and the most versatile amphibious machine. It behooves the designer to keep it unencumbered with excessive complexity and highly capable and efficient to fulfill its promise of great utility.

The Evolution of Aircraft Maintenance

I HAVE read with considerable interest Mr. Kessler's paper *The Evolution of Aircraft Maintenance*, which appeared on pages 178 to 183 in the May, 1960, issue of the JOURNAL, and I regret that I must take exception to the implication made in the "State of the Art and Philosophy" that the dramatic advance in the art of maintenance is attributable solely to the "repair by replacement" concept.

There is no denying that this concept has been a major factor, but I cannot agree that it has been *the* major factor as stated in the Conclusion at the top of page 183. To support this view, I would submit CPAL experience with the DC-6B aircraft. The following figures have not changed significantly through two changes of the maintenance system (increases in both minor and major check periodicity), through three changes to engine overhaul periodicity and, of course, many changes of individual component overhaul periodicities:

Type of Work	*Man Hours/Flying Hours*	*Per cent*
Airframe maintenance	6.08	52.0
Engine repair/overhaul	1.50	13.0
Rotables repair/overhaul	3.43	29.5
Other labour	.60	5.5
Totals	11.61	100%

These figures are fairly representative of all airlines operating this equipment. Since CPAL make use of subcontractors, whereas UAL do not, it is to be expected that with UAL the rotables labour content would be lower than the above. The foregoing would indicate that the measures of efficiency referred to in the paper, and illustrated in Figures 1 and 2, must also reflect improvement in other areas, since the other areas contribute very largely to the whole picture.

I believe that the single, most important factor evidenced during the past ten or so years, is the use of "rational approach" to aircraft maintenance. The application of modern analytical methods of Industrial Engineering. The rational approach has been applied to *all* facets of aircraft maintenance (including but not limited to the reliability of components or rotables), in order to minimize over-inspection, to increase productivity, to raise the standard of quality and to improve reliability of the whole aircraft, and the regularity of its operation. The aircraft is greater than the sum of its individual parts. This has never been truer than in its application to jet aircraft. Many of the airlines in their maintenance planning for this latest type of aircraft, are paying more attention to the "systems concept" (for the want of a better name). Without wishing to be forward in any way, I would refer to the paper *Airline Planned Maintenance* (1958 Mid-season Meeting of the CAI), which in my opinion, places the repair by replacement concept in proper perspective.

Vancouver, B.C. R. J. MCWILLIAMS

Mr. Kessler has replied:

IN spite of Mr. McWilliams' comments, I still contend that "the repair and replace or rotable component concept has been the major factor in the advance of the (aircraft) maintenance art" because it provided the basic environment in which all the other factors, such as the "rational approach", were able to operate. Under a complete disposal-at-failure concept it would have been most difficult or even impossible for these other factors to even germinate.

Washington, D.C. I. J. KESSLER

Propulsion Systems for Space Travel

In his paper *Propulsion Systems for Space Travel*, which appeared in the October, 1959, issue of the Journal, Professor Ribner has an interesting derivation which equates characteristic velocity to the square root of firing time and a non-dimensional constant. In the derivation a weakness is noted in setting $\dot{m}V_j^2 = KE$ by defining the power as that occurring in a unit time.

Another approach at this point yields a more reasonable result. The derivations included are the following, defining energy or power as thrust × velocity with appropriate substitution.

Powerplant comparison for ideal ΔV in space (zero drag and gravity losses)

Assume $P = km_e$ where P is propulsive power, k is a proportionality constant, m_e is engine mass

Thrust, $T = \dot{m}V_j$, where $\dot{m}$ is mass flow (fuel flow), V_j is exhaust velocity

Fuel mass, $m_f = \dot{m}t$ where t is firing time $= Tt/V_j$

$$m_e + m_f = P/k + \dot{m}t = T\left(V_j/k + \frac{t}{V_j}\right)$$

We wish to optimize $m_e + m_f$ as a $f(V_j)$

$$\frac{\partial(m_e + m_f)}{\partial V_j} = T\left(\frac{1}{k} - \frac{t}{V_j^2}\right) = 0$$

$$t = V_j^2/k = g^2 I_{sp}^2/k$$

expressing k' as watts/lb ft lb/sec $= \frac{746}{550}$ watts

$$t_i = 1.355\, gI_{sp}^2/k' = 43.6\, I_{sp}^2/k'$$

Note for chemical rocket:

$$t_i = \frac{V_j^2}{k} = \frac{V_j^2}{P/m_e} = \frac{V_j^2}{\dot{m}V_j^2/m_e} = \frac{m_e}{\dot{m}} = \frac{w_e}{\dot{w}}$$

For Rockets	w_e/w	$\dot{w}$
RP − LOX	0.1	0.0145 w
H_2 − LOX or F_2	0.08	0.0109 w
Nuclear	~0.2	~0.005 w

Comparison Based on 0.1 w Payload (or next stage)

System	k' watt/lb.	I_{sp}	t_{ideal}	t_{real}*	a_{avg}+	V/stage** with 0.1 w payload ft/sec
Chemical						
LOX − RP	5.1×10^6	300	7	56	277 (8.6 g)	15,500
LOX or F_2 − H_2	8.72×10^6	400	7.35	75.4	292 (8.1 g)	22,000
Nuclear—100 to 1,000 T	8.7×10^6	860	40	140	238 (7.4 g)	33,300
Plasma	100	4,000	$6.97 \times 10^6 = 91.6$ days		0.05	350,000
Ion	100	20,000	$1.745 \times 10^7 = 202$ days		0.004	70,000
Photon	100	3×10^7	$3.93 \times 10^{14} = 1.24 \times 10^7$ yrs		3×10^{-7}	1.18×10^7
Solar	1,000	∞	(too long)		→ 0	→ lim. $f\left(\frac{\epsilon}{r_o\rho}\right)$

* Note that our conditions imply $\dot{w}t_i = w_f = w_e$. Thus we correct t_{ideal} to a real value from the relation $t_{real} = t_{ideal}\, w_f/w_e$. Where w_f/w_e is obtained from practice or current design analysis. For the last four systems insufficient design data is available; so we arbitrarily set $t_{ideal} = t_{real}$.

\+ a_{avg} is found from $\Delta V/t_{real}$ for the first three systems and is given from reference data for the last four systems.

** ΔV is found from $\Delta V = gI_{sp}\, ln\, (m_o/m_f)$ for the first three systems.
$\Delta V = a_{avg}t$ for the last four systems.

Also of considerable interest are the firing times and stage velocity obtained for the more exotic forms of space propulsion by assuming $t_i = t_r$. It certainly eliminates some of the more widely discussed electrical propulsion methods.

Thus, the more reasonable substitution in Professor Ribner's derivations gives us a quite useful index of rocket system performance which should be of interest to CAI members and others working in the field.

San Diego, Calif. D. C. Weiss

Dr. H. S. Ribner has replied

THE derivation in question[1] sought to determine for a given travel time the rocket jet velocity that would minimize the sum (fuel weight plus engine weight) for the journey. The derivation is essentially that of W. E. Moeckel[2]: the former differs only in the use of jet velocity V in place of specific impulse I as basic variable, and in notation. However, I will undertake a reply.

Mr. Weiss criticizes the statement[1] jet power $P = (\frac{1}{2})mV^2$ (m = mass flow rate) and employs instead twice this value for P. Nevertheless, the first value would appear to be correct, being the flux of kinetic energy per unit time.

In his letter Mr. Weiss has appended an interesting chart comparing rocket performance characteristics. This would be more useful with further clarification. His computation yields that time t_1 of powered travel for which the given jet velocity V (or V_j) is optimum: i.e., minimizes the rocket weight for the journey. (It is noted that his relation $t_1 = m_e/m$ is correct, the factor of 2 having cancelled out.)

REFERENCES

(1) Ribner, H. S. — *Propulsion Systems for Space Travel*, CANADIAN AERONAUTICAL JOURNAL, VOL. 5, NO. 8, OCTOBER, 1959.

(2) Moeckel, W. E. — *Propulsion Methods in Astronautics*, ADVANCES IN THE AERONAUTICAL SCIENCES, PROCEEDINGS OF FIRST INTERNATIONAL CONGRESS IN THE AERONAUTICAL SCIENCES, MADRID, PERGAMON PRESS, NEW YORK, 1959.

Toronto, Ont. H. S. RIBNER

SECOND INTERNATIONAL CONGRESS IN THE AERONAUTICAL SCIENCES

Zurich, Switzerland: 12th - 16th September 1960

FURTHER to the notice published in March the following is the programme of the Second International Congress in the Aeronautical Sciences. The technical sessions will be held in the Grosser Horsaal für Experimentalphysik of the Eidgenössische Technische Hochschule, Gloriastrasse 35, Zürich 6. Application and hotel reservation forms can be obtained from the Secretary CAI.

Monday, 12th September 1960
10.00 a.m.

OPENING SESSION

Daniel and Florence Guggenheim Memorial Lecture

The Role of Entropy in the Aerospace Sciences
Jakob Ackeret, Prof., Institut für Aerodynamik,
Eidgenössische Technische Hochschule, Switzerland

2.00 p.m.

HYPERSONIC FLOW

Possibilités et limites actuelles de la théorie des écoulements hypersoniques
Jean Pierre Guiraud,
Ingénieur de Recherches, ONERA, France

A Paper to be Presented by the Academy of Sciences, USSR.

The Uses of Shock Tubes for Research on Hypersonic Flow
D. W. Holder, Dept. Ch. Scien. Officer, and
D. L. Schultz, Prin. Scien. Officer, Natl. Physical Lab., UK

A Paper to be Presented by the Academy of Sciences, USSR

2.00 p.m.

BOUNDARY LAYER FLOW

Beiträge zur Theorie der dreidimensionalen Grenzschichten
J. A. Zaat, Nationaal Luchtvaartlaboratorium, Holland

Instability of Laminar Boundary Layers
J. T. Stuart, Prin. Scien. Officer, Aerodyn. Div.,
Natl. Physical Lab., UK

Some Aspects of Boundary Layer Transition at Subsonic Speeds
Itiro Tani, Prof.,
Aeronautical Res. Inst., Univ. of Tokyo, Japan

Boundary Layer Transition at the Leading Edge of Thin Wings and its Effect on General Nose Separation
R. A. Wallis, Sr. Scien. Officer, Australian Def. Scien. Svce.,
Aeronautical Res. Labs., Dept. of Supply, Australia

Boundary Layer Separation at High Speeds
A. Naumann, Prof.,
Deutsche Versuchsanstalt für Luftfahrt, Germany

Tuesday, 13 September
8.30 a.m.

BOUNDARY LAYER, TRANSONIC AND SUPERSONIC FLOW

Aircraft Shapes and Their Aerodynamics for Flight at Supersonic Speeds
Dietrich Küchemann, Head, Supersonics Div.,
Royal Aircraft Estab., UK

Aerodynamic Design of Swept Wings and Bodies for Transonic Speeds
R. C. Lock and E. W. E. Rogers,
Prin. Scien. Officers, Aerodyn. Div., Natl. Physical Lab., UK

The Design of Wing Sections for Swept Wings at Transonic and Supersonic Speeds
H. H. Pearcey, Sr. Prin. Scien. Officer,
Aerodyn. Div., Natl. Physical Lab., UK

A Paper to be Presented by the Academy of Sciences, USSR

8.30 a.m.

FATIGUE OF MATERIALS

Stress Corrosion Cracking of High Strength Steel — or Hydrogen Embrittlement
Ivar Weibull, Head of Materials Lab.,
Saab Aircraft Co., Sweden

Etude microscopique de la fissuration par fatigue a haute fréquence
François Girard, Ingénieur de Recherches, ONERA, France

The Notched Fatigue Properties of High Tensile Steels
W. A. Morgan, Hd., and R. K. Buhr, Sr. Scien. Officer,
Ferrous Metals Sect., Phys. Metallurgy Div.,
Dept. of Mines and Tech. Surveys, Canada

Some Aspects of Fatigue in Aircraft Structures
J. Schijve, Structs. and Mtls. Dept.,
Natl. Aeronautical Res. Inst., Holland

2.00 p.m.

SUPERSONIC FLOW

A Paper to be Presented by the Academy of Sciences, USSR

Theoretical and Experimental Studies of Cambered and Twisted Wings Optimized for Flight at Supersonic Speeds
C. E. Brown, Ch., Theoretical Mech. Div., E. B. Klunker,
and F. E. McLean, Aeronautical Res. Engrs.,
Langley Res. Center, NASA, USA

Some Experimental Results of Generating High Frequency Oscillating Shock-Waves and Oscillating Shock-Wave Boundary Layer Interaction at Supersonic Speeds
Wladyslaw Fiszdon, Prof. of Aeronautics,
Tech. Univ. Warsaw, Poland

A Paper to be Presented by the Academy of Sciences, USSR

2.00 p.m.

AEROTHERMOCHEMISTRY

Some Contributions to Laminar Flame Theory
Gregorio Millan, Advisor, and Ignacio da Riva, Aeronautical Engr., Instituto Nacional de Técnica Aeronáutica, (INTA) Spain

Etude de la combustion dans les fusées à lithergol
André Moutet, Chef de Groupe, and Marcel Barrère, Chef de Division, ONERA, France

Effect of a Shock-Wave in a Burning Solid Propellant
Ellis M. Landsbaum, Res. Group Supvsr.,
Solid Propellant Rockets Sect., Jet Prop. Lab., CIT, USA

Elucidation of Combustion Instability in Solid Propellant Rockets
Seiichiro Kumagai, Prof., Dept. of Aeronautics,
Faculty of Engrg., Univ. of Tokyo, Japan

A Paper to be Presented by the Academy of Sciences, USSR

Wednesday, 14 September
8.30 a.m.

NONSTATIONARY TRANSONIC FLOW

Non-Stationary Transonic Flow Past Airfoil and Revolution Bodies at a Zero Angle of Attack
Carlo Ferrari, Prof.,
Politecnico, Centro Dinamica dei Fluidi, Italy

A Paper to be Presented by the Academy of Sciences, USSR

8.30 a.m.

AIR TRANSPORT

Operations Research in the Basic Design of YS-11 Transport Airplane
Hidemasa Kimura, Prof. of Aeronautical Engrg., Faculty of Engrg., Nihon Univ.; Jiro Kondo, Prof., Tokyo Univ.; and Shizuo Kikuhara, Tech. Advisor,
Shin-Meiwa Indus. Co., Ltd., Japan

Airline Economy in the Turbine Era
Franklin W. Kolk, Dir., Engrg. R&D,
American Airlines, Inc., USA

10.15 a.m.

GENERAL LECTURES

Physik des Jet-Stream
Walter Georgii, Dir., Deutsche Forschungsanstalt für Segelflug, Institut für Flugforschung, Germany

The Aerodynamics of Jet Flaps
John Williams, Suptndt. Low-Speed Tunnels Div.,
Aerodyn. Dept., Royal Aircraft Establ., UK

Thursday, 15 September
8.30 a.m.

MAGNETOFLUIDDYNAMICS

Sub- and Super-Alfvenic Flows Past Bodies
W. R. Sears, Dir., and E. L. Resler, Jr., Prof.,
Grad. School of Aeronautical Engrg., Cornell Univ., USA

Aerophysical Studies at Hypersonic Velocities in Free Flight Ranges
C. J. Maiden, Hypersonic Physics Group,
Canadian Armament Res. and Dev. Establ., Canada

Magnetofluiddynamic Shear Turbulence
Luigi G. Napolitano, Assoc. Prof. of Aerodyn.,
Univ. of Naples, Italy

Magnetoaerodynamics in Japan
Isao Imai, Prof., Dept. of Physics, Faculty of Science,
Univ. of Tokyo, Japan

8.30 a.m.

STRUCTURES AND FATIGUE

Statistical Methods for Fail-Safe Design with Respect to Fatigue of Aircraft Structures
Bo K. O. Lundberg, Dir.,
The Aeronautical Res. Inst. of Sweden

A Method of Self-induced Alternating Loads Alleviation of Airframes
F. Misztal, Prof., Politechnical Univ., Poland

Einfluss des Start-Landelastwechsels auf die Lebensdauer von böenbeanspruchten Flugzeugflügeln
Ernst Gassner, Laboratorium für Betriebsfestigkeit, and Karl F. Horstmann, Maschinenfabrik Carl Schenk, G. m. b. H., Germany

Protection of Aircraft Structures Against High Temperatures
Wilfred M. Dukes, Ch. of Struc., Aero-Space Dept.,
Niagara Frontier Div., Bell Aircraft Corp., USA

2.00 p.m.

FLOWS WITH CHEMICAL REACTIONS

Limites en vitesse et altitude des propulseurs utilisant l'air atmosphérique
Albert Goslan, Chef de Departement (Propulsion),
Nord-Aviation, France

Hypersonic Ramjets
Donald L. Mordell, Dean, Faculty of Engrg., and J. W. Swithenbank, Assoc. Prof. of Mech. Engrg.,
McGill Univ., Canada

Research Problems on Recombination and Condensation in Nozzles
Walter T. Olson, Ch. Propulsion Chem. Div.,
Lewis Res. Center, NASA, USA

Schliereninterferenzaufnahmen von Kopfwellen und Grenzschichten dissoziierter Gase
Herbert Oertel, Physiker, Deutsch-Französisches Forschungsinstitut Saint-Louis, France

2.00 p.m.

AEROELASTICITY

Predictions of Lifting Surface Flutter at Supersonic Speeds
Holt Ashley, Assoc. Prof. of Aeronautics and Astronautics, MIT; Walter Mykytow, Asst. Ch., Dynamics Br., Aircraft Lab., Wright Air Dev. Div., USAF; and John Martuccelli, Res. Engr., Aeroelastic and Struc. Res. Lab., MIT, USA

Elastic Stability and Vibration of Slender Body in Supersonic Flow
Sylwester Kaliski, Prof., and Jerzy Kacprzynski, Master Engr., Dept. of Vibrations, Polish Academy of Sciences, Poland

Détermination des vitesses critiques transitoires d'un engin supersonique en vol accéléré
Robert Mazet, Prof., Dir. Scientifique, and Eugene Bonneau, Chef de Groupe de Recherches, ONERA, France

Vibrations of Viscoelastic Plates and Shells due to Rapid Heating
Witold Nowacki, Prof., Polish Academy of Sciences, Poland

Friday, 16 September
8.30 a.m.

ENTRY FROM SPACE

Manned Re-Entry at Super-Satellite Speeds
Robert B. Hildebrand, Ch., Advanced Syst. Res.,
Aero-Space Div., Boeing Airplane Co., USA

Effects of Non-Equilibrium Flows on Aerodynamic Heating During Entry into the Earth's Atmosphere from Supercircular Orbits
Glen Goodwin, Ch., and Paul Chung, Res. Scien.,
Heat Transfer Br., Ames Res. Center, NASA, USA

Radiative and Ablation Cooling for Manned Re-Entry Vehicles
Leonard Roberts, Aeronautical Res. Engr., Langley Res. Center, NASA, USA

Sur l'aérothermodynamique des parois fongibles
Th. Moulin and J. J. Bernard, ONERA, France

8.30 a.m.

AEROSPACE MEDICINE

Zur Frage der Auswahlmethoden für Besatzungen unkonventioneller Flugkörper
Siegfried Ruff, Prof., Institut für Flugmedizin, Deutsche Versuchsanstalt für Luftfahrt e. V., Germany

Body Susceptibility to High Accelerations and to Zero Gravity Condition
Rodolfo Margaria, Prof. of Physiology, Institute of Human Physiology, Medical School, Univ. of Milan; and T. Gualtierotti, Institute of Human Physiology, Univ. of Sassari, Italy

A Review of Biologic Exposures to Space Environments
Brig. Gen. Don Flickinger, Asst. to Commander for Bioastronautics, USAF (MC), USA

Comportement de quelques fonctions perceptives et motrices pendant le passage de deux à zéro G, obtenu au moyen de la tour de subgravité. Influence de l'entraînement
Tomaso Lomanaco, Dir. des Services de Santé de l'Aviation Militaire, Corps de Santé, Aviation Militaire Italienne, Aristide Scano, IAF (MC), and Franco Rossanigo, IAF (MC), Centre d'Etudes et de Recherches de Médécine Aéronautique, Italy

2.00 p.m.

SPACE FLIGHT

Power Generation Systems for Use in Space
Henry O. Slone and Seymour Lieblein, Aeronautical Res. Engrs., Nuclear Reactor Div., Lewis Res. Center, NASA, USA

Guidance of Space Vehicles by Radio Measurements and Command
A. R. M. Noton, Group Supervisor, Jet Propulsion Lab., CIT, USA

Discoveries from Satellite Orbits
D. G. King-Hele, Prin. Scien. Officer, Royal Aircraft Establ., UK

CLOSING SESSION

SAE INTERNATIONAL CONGRESS AND EXPOSITION OF AUTOMOTIVE ENGINEERING

Detroit, Michigan: 9th - 13th January, 1961

THE SOCIETY of Automotive Engineers has invited the Canadian Aeronautical Institute to participate in an International Congress and Exposition to be held in Detroit next January. It is understood that some 30 scientific and engineering societies from 16 countries will be taking part; some 150 papers will be presented and there will be a large exhibition of engineering products. In SAE usage, "automotive" means self-propelled and the Congress is therefore open to all technical aspects of both ground and flight vehicles.

The SAE has invited the submission of papers by members of the Institute, for presentation at this Congress. Before accepting any papers, the SAE Planning Committee would like to review summaries of them and they have prepared a special form for this purpose. A small supply of these forms is held at CAI Headquarters and they can be furnished on request. To meet the planning schedule, summaries must be submitted to SAE Headquarters, New York, by the **30th June, 1960.**

The subjects in which the SAE has expressed particular interest are listed below.

Combustion Research for Piston, Turbine Engines and Rockets

Air Cargo Loading Systems
(Sub-topic: Alternative methods of loading and stowing, special equipment requirements and economics for various types of service)

Advances in Airport Design

Blind Landing and Approach Systems for Conventional Aircraft

Recent Developments in High-Temperature Anti-Friction Bearings and their Lubrication

High-Strength, Extreme-Temperature Structures

Ground Support Equipment for Aircraft (such as starters, refuelers, etc)

High-Speed Wheel and Brake Design and Maintenance

Propulsion Drive Lines for V/STOL Aircraft
(Sub-topic: Including cross-shafting over-running clutches and gears for multi-engine installations)

Application of Nuclear Radiation for Production Control

Effects of High-Energy Radiation on Materials of Engineering Interest

Application of Nuclear Radiation for Research and Development

Manufacturing Processes
(Sub-topics: Special forging machines: Cold Forming)

Automation
(Sub-topic: Degree of integration of operations into a single transfer machine; partial automation such as automatic loading of single machines)

Fuel Cells

C.A.I. LOG

SECRETARY'S LETTER

HALIFAX-DARTMOUTH

To complete my round of the Branches this year I visited the Halifax-Dartmouth Branch on the 27th April and attended their Annual General Meeting. Unfortunately the President was unable to make the trip with me. He had intended to, but the Branch had to change the date originally set for the meeting to a date when the President happened to be out of the country.

In his Chairman's Report, Mr. R. Wallworth gave an impressive account of the Branch programme and, having had a hand in the building and unveiling of our Monument at Baddeck last June, the Branch has experienced a very eventful year. They are faced, of course, with the perennial difficulty of getting speakers, but their own members have given them a few good papers; they are to be congratulated on their resourcefulness.

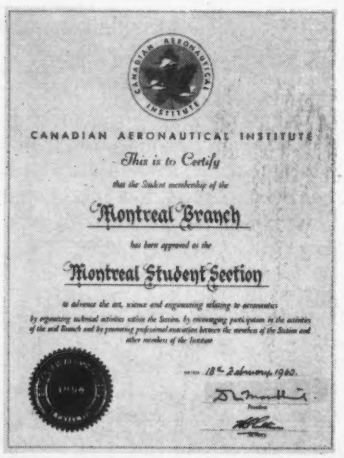
ON GIVING PAPERS

Within the next month or two the Branches will be making plans for the coming season and I am sure that they would welcome offers of papers from their members. One of the purposes of the Institute is to provide speakers; another, and no less important, is to provide audiences. The presentation of papers is part of a man's professional life and it is a rewarding experience. Not only does he get an opportunity to say his piece and express his opinions but he finds that in preparing the paper he disentangles some of his own thinking and, in the discussion following his talk, his ideas are developed and amplified.

I am quite serious when I say that every member should think about it. As I have said in a previous letter, it is a habit that we have got to cultivate in this country. To those who have not given papers before I would commend Branch meetings as a good starting point. There you will be among people who, by their very contact with your daily work, will be interested in what you have to say about it. If on the Branch anvil it hammers out into a good thing, try it on the Journal or submit it for presentation at an Institute Meeting.

STUDENT SECTIONS

We have introduced Certificates for Student Sections, to give a little more formality to this branch of our activities. There are now Student Sections attached to the Toronto, Vancouver, Ottawa, Calgary and Montreal Branches – in that order of formation – and I hope that others will be formed. Where geographical conditions permit it is desirable that there should be only one Section at any one Branch, so that Students of perhaps two or three universities can get together in a common group; for example, the Montreal Student Section has members in McGill, Sir George Williams and Ecole Polytechnique. However the Vancouver Branch Students at the Canadian Services College, Royal Roads on Vancouver Island, obviously cannot share a Section with the Students at the University of British Columbia on the mainland. (There is no Section at UBC as yet, but I hope that there soon will be.)


CANADIAN AERONAUTICAL INSTITUTE

This is to Certify

that the Student membership of the

Montreal Branch

has been approved as the

Montreal Student Section

to advance the art, science and engineering relating to aeronautics by organizing technical activities within the Section, by encouraging participation in the activities of the said Branch and by promoting professional association between the members of the Section and other members of the Institute

— 18th February, 1960.

The Student movement is most important and I shall be very glad to help and advise any Branch that wants to get a Student Section going. During the summer months, before the academic year starts, we have a little time to do some planning.

BRANCHES

Halifax-Dartmouth

Reported by J. W. Milman

March Meeting

The March meeting of the Branch was held in the Chief Petty Officers' Mess, HMCS Shearwater, on Wednesday 16th March, 1960. Mr. R. Wallworth, Branch Chairman, was in the chair. 37 members and guests attended the meeting.

Mr. Wallworth presented the Annual Student Award to Mr. F. A. Christie, a native of Amherst, N.S., who graduated in 1955 from Dalhousie University with a B.Sc and Diploma of Engineering. Mr. Christie is expected to graduate this year with Honours in mechanical engineering from Nova Scotia Technical College. He has recently been awarded an Athlone Fellowship for study in jet propulsion in the UK. He plans to spend one year at a research and development station, followed by two years studying at Imperial College, London, for his Masters degree. During the summers, Mr. Christie was with the RCAF as a URTP student navigator, earning his "Wings" in August, 1958.

The speaker for the evening, Surgeon LCDR E. R. Keirsted, RCN, Flight Medical Officer at HMCS Shearwater, was introduced by the Chairman. In his introduction, Mr. Wallworth mentioned that LCDR Keirsted has recently completed a year's residency in Flight and Space Medicine at Pensacola Naval Base in the United States. The title of LCDR Keirsted's talk was "Medical Aspects of Space Flight".

In his opening remarks, LCDR Keirsted stated that aviation medicine is a specialized field dealing with the physiological function and dynamics of aircrew personnel and passengers under flight conditions. It is also concerned with the devices that assist in compensating for the stresses imposed by flight. Physiologically, 50,000 ft is generally considered an important altitude for, below this, problems lie in the field of aviation medicine, and above this, in the field of space medicine.

Not many years ago aviation medicine experts rather boldly intimated to the aeronautical engineers that if they could provide the vehicle, there would be no problem keeping man alive at very high altitudes. However, as we consider sending man into space and possibly into orbit, the medical problems, which are more numerous and difficult, are not by any means solved and vehicles have already been produced to travel into space and return, with no harm to the occupants.

Student Award presentation
l to r: Prof. O. Cochkanoff, Mr. F. A. Christie, Mr. R. Wallworth (Chairman) and Prof. M. L. Bedser.

Physical characteristics of the atmosphere including those in the Troposphere, Stratosphere, Ozonosphere (mesosphere and thermosphere), Ionosphere ("*D*", "*E*", "F^1" and "F^2") and Exosphere were then enumerated.

Actual problems of space flight were considered under the headings of hypoxia and methods of assuring sufficient oxygen to an astronaut: full pressure suits; complex acceleration patterns; extremes of temperature; possible collision and resultant penetration of a space vehicle by meteorites; visual problems; toxicology of gaseous and airborne substances originating in the body; food supply; difficulty in eating in the weightless condition; water conservation and reconstitution from urine and other sources; exposure to cosmic and other radiation; and escape in the event of an emergency.

In conclusion, LCDR Keirsted described at some length the space flight of our first astronauts, Old Reliable, Able and Baker, including the physical set-up in the nose cone, their physiological reaction to the flight and lack of any ill effects whatsoever from their eventful journey into space.

After an interesting and stimulating question period, LCDR Keirsted was thanked by Prof. O. Cochkanoff.

Montreal

Reported by A. M. Scott

March Meeting

The regular monthly meeting was held at the Airlines Restaurant, Montreal, on March 16, 1960, Branch Chairman, Mr. R. F. O. Smith, presiding. The dinner was attended by 56 members and guests including CAI Secretary, Mr. H. C. Luttman.

The speaker of the evening, Mr. P. Kearvell of IATA, was introduced by Mr. A. M. Scott. Mr. Kearvell, speaking on the "First Year's Operational Experience with the Big Jets", began his lecture by saying that the introduction of civil jet aircraft had been an unqualified success which was, without doubt, due to the extensive planning carried out by the airlines since the aircraft had been ordered. In this respect they had received a large measure of assistance from the industry as a whole and the extent of this cooperative effort, to ensure that the jets were launched successfully, was probably unique.

In this regard special mention should be made of the assistance and advice contributed by the military authorities and in particular by Strategic Air Command. In many cases they had been the only sources of practical operating experience and this, which they freely related during IATA Technical Conferences, had been of inestimable value. They had given airlines indications of

likely trouble areas and, as a result, it had been possible to take early preventative measures.

For various reasons it was still not possible to operate civil jet aircraft at their optimum and both airlines and their passengers were therefore being deprived of the benefits of the form of transportation.

In very broad terms, the major responsibility for this could be said to be the problem of the diminishing airspace. Increased civil and military traffic was making greater demands on the available airspace which were accentuated by the performance characteristics of modern aircraft. Mr. Kearvell illustrated, by means of a slide, typical examples of military airspace blockages which restrict the freedom of civil jet operations resulting in increased flight time and, in some cases, the necessity for intermediate refuelling stops which would otherwise have been unnecessary.

Another big factor affecting jet operations at present was the inability of the present Air Traffic Control system to accommodate the operational requirements of these aircraft. An intensive and encouraging program of research and development to improve the ATC system was in progress. However, improvement in this field would of necessity be evolutionary rather than revolutionary, and it would be some time before this problem was satisfactorily solved. With regard to ground handling, considerable improvements were required at many airports in order to facilitate the flow of passengers and their baggage to and from the aircraft, since inefficiency in this phase of the operation defeated the objective of these aircraft, which was to offer speedy transportation. Improved facilities were also required to enable an uninterrupted flow of traffic to and from the runway by the provision of adequate taxiways and by-passing facilities.

While the ultimate objective of airlines was all-weather operation, initial experience had indicated that for jet aircraft, a visual approach and landing was virtually a thing of the past. Most airports now provided adequate facilities, on at least one runway, for landing under bad weather, low visibility conditions. However, there was a requirement to provide some form of guidance on all runways to be used by jet aircraft for landing, which would enable them to align themselves with the runway and establish themselves on the optimum glide slope.

Visual Glide Path indicators had been developed which appeared to be operationally satisfactory. Airlines were keen that these should be evaluated as soon as possible and the most suitable types installed with a minimum of delay.

At the conclusion of the talk Mr. J. T. Dyment thanked the speaker.

April Meeting

The Annual Joint CAI/SAE Meeting was held in the Sheraton-Mount Royal Hotel on the 11th April at 6.15 pm, Mr. A. H. Paton, Chairman of the Montreal Section of the SAE, presiding.

The speaker of the evening, Dr. D. L. Mordell was introduced by Mr. J. Hammond, SAE.

Dr. Mordell opened his talk by defining the scope of his paper "Air Breathing Engines for Hypersonic Transports". By "air breathing" he meant engines which utilized the atmosphere for the bulk of their propellant and by "hypersonic transpots" he meant vehicles with air lifting surfaces operating at speeds between 3,000 and 25,000 knots.

The historical stages of aircraft development could be considered as follows:

Stage 1—the early flying machines up to approximately 1930

Stage 2—the propeller driven aircraft from the DC-3 to the Viscount and Britannia

Stage 3—the jet propelled subsonic aircraft embracing the Comet, DC-8 and 707 etc

Stage 4—the *M*3 transport aircraft

Stage 5—aircraft in the *M*6-*M*8 range

Stage 6—aircraft in the range *M*10 and upwards to escape velocity

Dr. Mordell made it clear that his paper did not cover the economics of these hypersonic aircraft in the last two stages, but was concerned with their technical feasibility. Possible flight in the atmosphere lay in a narrow corridor of altitude and velocity between limits of insufficient air and too much heat. There was already good evidence to indicate this corridor existed which could permit flight up to 300,000 ft altitude and 25,000 fps. The justification for air breathing engines was exemplified by the propellant requirements for an aircraft such as the DC-8 which on a trans-Atlantic flight required some 30,000 tons of propellant, of which 29,950 tons was supplied by the atmosphere, and only 50 tons was fuel carried in the aircraft. The existing jet engine, it was considered, could be developed up to speeds of *M*3 and *M*4, at which point the stagnation temperature at the compressor inlet established a limiting factor.

The speaker considered the next step would be the ramjet. The limitation on the ramjet would be the upper limits of combustion due to disassociation. This would occur at about *M*7 where the stagnation temperature would have reached the point at which heat could not be released to the air by chemical means. The next development, it was felt, would be the supersonic combustion ramjet in which the air velocity was not appreciably reduced prior to the addition of fuel. At these speeds the losses involved in adding heat are less than the losses involved in slowing the air down. It was anticipated that for speeds about *M*6, fuel would be added to air which had been slowed down to about *M*4.

Is supersonic combustion possible, and what evidence is there to support this? It was the speaker's opinion that it was feasible; there was already practicable evidence from tests carried out in various laboratories. It was agreed that this is a long way from being able to produce an actual engine, but at least it indicated the feasibility. Thermal efficiencies of up to 55% were considered possible.

The speaker indicated that the logical development of such a supersonic ramjet was in fact not to have an engine, but to burn the fuel externally under the wing of the aircraft. It was anticipated that this would have the added benefit of improving the lift/drag ratio – perhaps up to 12:1.

Again, it was emphasized that, while there were obviously practical difficulties, this concept was based on tried physical tests.

With regard to the application of such aircraft, the speaker considered that except on the extremely long ranges there was little justification for a commercial transport, but it became more attractive when one considered possible military transport uses. However, he felt there was another field in which such a vehicle would prove extremely useful and economic; this was as a launcher for a single-stage rocket which would then be capable of attaining orbit conditions. On present calculations such a machine should be capable of putting into orbit a mass 13 times greater per lb of vehicle weight than for a ground launched multi-stage rocket. The other advantage would be, of course, that the aircraft could then return and launch additional rockets.

Dr. Mordell pointed out that the cost of such a project did not appear to him to be within the capability of a country like Canada, but he did feel that Canada could make a significant contribution by proving the principles in a satisfactory way. At McGill University there was already a small hot hypersonic wind tunnel in which it was hoped to prove the supersonic combustion part of an

engine for such a vehicle. The next step would be to make a model of the aircraft and this could be proved by launching from a gun, such as was available at CARDE. Tests such as these were relatively inexpensive and could go a long way to proving the feasibility of the full-size vehicle.

Dr. Mordell concluded by stating that in spite of advances in rocketry he considered that there was still a place for the air breathing engine where the flight path passed through the atmosphere, and provided a much better method of mass transportation than the vehicle with self-contained combustion.

The question period, led by Mr. F. C. Phillips, raised points on the type of fuel Dr. Mordell was considering and whether it was still considered that wings would be necessary in such a vehicle. The ideal fuel was considered to be liquid hydrogen. With regard to wings, these were considered essential both for the landing and takeoff conditions and would also provide a useful contribution during high speed flight. A variable sweep back wing would possibly be the solution.

Toronto

Reported by C. F. de Jersey

April Meeting

Imagine the result of exposure to sudden decompression of the commuter type public, in a modern high-altitude aircraft: scanty briefing, panic caused by noise, sudden fogging of the cabin interior, rapid change of aircraft altitude, difficulty in adjusting an oxygen mask made for 'universal' faces and loss of normal physical control due to anoxia. To this can be added the plight of mothers with children and aged passengers completely unable to fend for themselves.

This was the theme of the paper presented by F/L A. G. Bryan of the Institute of Aviation Medicine, RCAF, to the Toronto Branch on 19th April.

The Chairman, Dr. J. H. T. Wade, welcomed the very small audience of 60 members and guests assembled in The De Havilland Aircraft Cafeteria, and asked G/C W. R. Franks, Scientific Advisor in Aviation Medicine to the Institute, to introduce the speaker.

This introduction was given with great pleasure and much pride, G/C Franks stated, for F/L Bryan had given himself unstintingly in the various experiments undertaken by the Institute. Considerable physical risk was always present in these experiments, and often severe measures had to be taken to restrain F/L Bryan from exposing himself to diagnostic experiments presenting great danger.

In his opening remarks, the speaker said that in the past only military personnel had been engaged in flying at altitudes where decompression was a possible hazard, however with the introduction of big jets in passenger service all over the world, all kinds of people of all ages and states of health were suddenly liable to exposure to the horror of sudden decompression at altitudes of 40,000 ft or above.

It was in this extremely hostile environment that the Air Force experiments were undertaken, first to study the effect on personnel and, if possible, find a rapid method of restoring normal consciousness.

The problems the speaker showed, were formidable; the fact that the 8,000 ft cabin altitude reaches 40,000 ft in under 15 seconds by the loss of a window, indicates the short time available for remedial measures.

F/L Bryan mentioned that between the years 1952-58 there had been 184 reported failures of cabin pressurization systems in passenger aircraft. The 'Comet' decompression failures had of course proved disastrous; however, most of the other instances involved aircraft flying at considerably lower altitudes and had therefore resulted in only a small loss of life.

The future might well be tragically different, since far bigger aircraft were carrying larger passenger complements at ever increasing altitudes.

Rapid decompression resulting in immediate loss of barometric pressure induces extremely rapid loss of consciousness, and is liable to cause permanent injury to the persons involved.

F/L Bryan interspersed his remarks with scenes from two films made at the Institute, covering some of the tests of simulated pressurization failure.

These amazing films showed the effects of sudden decompression upon young, healthy, fully trained RCAF personnel, who are shown to be incapable of performing the simplest tasks within a frighteningly short lapse of time.

The experiments indicated that, although the average subject involved in the tests had approximately 18 seconds of consciousness, in order to preserve useful consciousness an oxygen mask had to be used within five seconds. Out of thirty tests, three people could not attach their oxygen masks properly after being subjected to a 40,000 ft atmospheric environment for only five seconds.

The unhappy results obtained from the experiments using available masks prompted the Institute staff to investigate a number of other methods.

To the audience, these investigations resulted in a method which seemed to fill the requirements most adequately. Under simulated decompression failure, a plastic bag having an oxygen outlet in the closed end was dropped over a victim's head, allowing the oxygen to flow freely over the head. Test showed that no fitting was necessary, and that only violent convulsions would remove it under operating conditions.

However, even this is not considered satisfactory to F/L Bryan and his associates, therefore experiments are still being undertaken.

After a lively question period the Chairman closed the meeting by thanking the speaker, and remarking that after listening to this paper he felt that the ox cart was after all damned good transportation.

The slate for the 1960-61 Branch Executive Offices had been mailed out as prescribed in the Regulations, and it was hoped that the election results would be available for announcement at the Annual General Dinner Meeting tentatively scheduled for Tuesday, 10 May.

Winnipeg

Reported by C. P. Gulland

April Meeting

75 members and guests attended a Dinner Meeting at the Winnipeg Flying Club on the 26th April. W/C J. C. Evans opened the meeting by welcoming the guests and reminding the members of the forthcoming election of the Branch Officers.

The speaker of the evening, Mr. P. G. Waite, Chief Sales Engineer, Turboprops, Rolls-Royce of Canada, was introduced by Mr. T. Kilpatrick, the Winnipeg Rolls-Royce Representative. Mr. Kilpatrick outlined the career of the speaker from apprenticeship in Halton through his association with Vickers, Napier and Rolls-Royce.

Mr. Waite commenced his paper entitled "The Tyne Engine" by tracing the background and history of the turboprop engines. In 1943 Rolls-Royce converted a Derwent turbojet engine into a turboprop called the "Trent". From this beginning the Dart and subsequently the Tyne engine developed. At the time of speaking, over 11 million hours experience had been logged on the Dart – a figure which increases at a rate of 5.5 hours every minute of the day.

By means of slides the speaker gave a quick coverage of the engine details. The engine is of the twin spool axial flow type. The compressor has 15 stages of compression – six low pressure and nine high pressure – giving an over-all pressure ratio of 13.6:1. The HP blades are manufactured in titanium and steel. The combustion section incorporates ten straight flow flame tubes each of which

is fitted with duple burners. The turbine is four stage, featuring extended root blading. Mr. Waite considered the extended root blading to be a major design improvement and showed that for identical turbine inlet temperatures, the blade root of the Nene and Derwent run at approximately 525°C whilst the Tyne is only 375°C. This comparatively low temperature together with air cooling permits the use of ferritic discs.

Following the engine description, Mr. Waite briefly explained other features of the engine such as the de-icing of the inlet guide vanes, the torque meter and negative torque limiting systems, and the engine control for the flight regime and the Beta system for ground operation.

The flight test program was first carried out with a single Tyne mounted in the nose of a Lincoln bomber. The second stage involved two Tyne engines powering a twin-engine Elizabethan aircraft. The third and present stage involves new airframes specifically designed to take this engine. Such an aircraft is the Vanguard and to date 3,500 flying hours have been logged.

The question period following Mr. Waite's paper was quite lively. Answering one question the speaker expressed the opinion that, even in this day of high speed jet transportation, there is still a place for the propeller driven machine. The economy of the Tyne engine will enable the designer to concentrate on large carrying capacity and slower, more luxurious aircraft which will operate at a lower cost per ton mile. The latest version of the Tyne engine, the Type 12, has been especially developed for use in the Canadair CL-44 cargoliner. The military version of this aircraft has been ordered by the RCAF.

Mr. L. Deane of Standard Aero Engines thanked the speaker on behalf of the Winnipeg Branch.

Cold Lake

Reported by F/O J. J. Francis

April Meeting

The April meeting of the Cold Lake Branch was held in the theatre of the Ground Instructional School on Monday, the 11th April, 1960.

The Vice-Chairman, S/L R. E. Zwicker, took over as Chairman now that Mr. J. B. Panton has left Cold Lake and the Branch is in the process of electing a new Executive for the coming season.

The attendance was small due to the changes taking place, as many of the members are being transferred and new members difficult to recruit. However S/L Zwicker introduced Major C. I. Taggart, Chief Instructor of Photographic Interpretation at the Canadian Joint Air Training Centre, Rivers, Manitoba.

Major Taggart gave a very interesting talk on the progress being made in the stereoscopic interpretation of information from air photographs and effectively demonstrated this process by the use of projectors and polarized viewing spectacles.

The speaker was thanked by S/L Zwicker and a discussion period followed.

COMING EVENTS

IAF

15th-20th August—*XIth International Astronautical Congress*, STOCKHOLM, SWEDEN.

ICAS

12th-16th September—*Second International Congress in the Aeronautical Sciences*, ZURICH, SWITZERLAND.

IAS/CAI

17th-18th October — *Annual Joint IAS/CAI Meeting*, QUEEN ELIZABETH HOTEL, MONTREAL.

SAE

9th-13th January, 1961 — *International Congress and Exposition of Automotive Engineering*, DETROIT, MICHIGAN.

SECTIONS

Astronautics

20th-21st October—*Canadian High Altitude Research Symposium*, CHATEAU LAURIER, OTTAWA.

APPOINTMENT NOTICES

Service Representatives: several field service engineering positions are available to applicants with aero engine experience. Those selected will receive specialized training on gas turbine engines. Apply as below.

Technical Assistants: duties will involve liaison with aircraft operators and field representatives and the compilation of necessary reports and recommendations.

Applicants with a technical and practical background preferably in aeronautical (engine) engineering and educated to the Higher National Certificate standard should apply in writing only, giving qualifications and an outline of previous experience, to: Assistant Personnel Manager, Rolls-Royce of Canada Ltd., Box 1400 St. Laurent, Montreal 9, P.Q.

MEMBERS

NEWS

A/C A. A. G. Corbet, F.C.A.I., has been awarded the Theodore C. Lyster Award for outstanding achievement in the general field of Aviation Medicine.

J. C. Charleson, M.C.A.I., has recently been appointed a Director of Aero Surveys Ltd.

V. G. Gibbard, M.C.A.I., has accepted a position as Service Representative with Rolls-Royce of Canada Ltd.

L. A. Kendrick, M.C.A.I., formerly Assistant Chief Inspector of Lucax-Rotax Ltd. has been appointed Quality Control Manager at Canadian Applied Research Ltd.

DEATH

It is with deep regret that we record the death of **Mr. J. J. Russell, M.C.A.I.**

Mr. Russell who died on the 16th May, 1960, was at the time of his death Assistant to the President, Fairey Aviation Company of Canada Limited, resident in Ottawa.

ADMISSIONS

At a meeting of the Admissions Committee, held on the 4th May, 1960, the following were admitted to the grades shown.

Associate Fellow

I. R. Cameron, A/Superintendent Explosives Wing, Can. Armament Research and Development Est., Quebec, P.Q.: *1431 Villars, Sillery, Quebec 6, P.Q.*

L. A. Dickinson (on transfer from Member)

Member

C. R. Chater, Technical Representative, Redifon Canada, Montreal, P.Q.: *c/o Wardroom, HMCS Shearwater, Dartmouth, N.S.*

W. P. Clark, Supervisor, Line Maintenance, Canadian Pacific Air Lines Ltd., Edmonton, Alta.: *10730 - 109 St., Edmonton, Alta.*

LCDR (E) (AE) D. W. Cumming, RCN, Assistant/Director of Aircraft Design and Production, A/CNTS (Air), RCN/HQ, Ottawa, Ont.: *Box 555, R.R. No. 1, Ottawa, Ont.*

A. M. Ferrey, Engineer 'A', Canadair Ltd., Montreal, P.Q.: *98 - 17th Ave. S., St. Eustache-sur-le-lac, P.Q.*

F/L D. A. Fretts (on transfer from Technical Member)

L. Groves, Flight Engineer, Canadair Ltd., Montreal, P.Q.: *4534 Earnscliffe, Montreal 29, P.Q.*

W. S. Jones, Research and Design Engineer, Redifon Canada, Montreal, P.Q.: *111 Thistle St., Dartmouth, N.S.*

A. A. P. McGowan (on transfer from Technical Member)

F/L J. Mitchell (on transfer from Technical Member)

J. B. Ogle, Engineer 'A', Canadair Ltd., Montreal, P.Q.: *11891 Michel Sarrazin, Apt. 22, Montreal, P.Q.*

F/S D. P. Robbins (on transfer from Technical Member)

R. W. Simpson (on transfer from Technical Member)

R. E. Stoddart (on transfer from Technical Member)

T. M. Watt, Sales Engineer, Canadair Ltd., Montreal, P.Q.: *Box 856, Ste. Rose, P.Q.*

Technical Member

J. B. Bradley (on transfer from Junior Member)

A. Bushell, Foreman, Foothills Aviation Ltd., Calgary, Alta.: *2127 - 27th Ave. S.W., Calgary, Alta.*

F/C B. D. Emery, RCAF, Sir George Williams College, Montreal, P.Q.: *Box 464, 39 Caille Ave., St. Bruno, P.Q.*

Z. W. Fedun (on transfer from Student)

B. G. Glew, Deputy Chief Inspector, Carriere & MacFeeters Ltd., Scarborough, Ont.: *15 Rosemount Dr., Scarborough, Ont.*

L. Ingle, Deputy Chief Inspector & Maintenance Instructor, Spartan Air Services Ltd., Ottawa, Ont.: *115 Meadowlands Dr., Ottawa 5, Ont.*

U. Okapuu, Junior Research Engineer, National Research Council, Div. of Mechanical Engineering, Ottawa, Ont.: *331 Brittany Dr., Ottawa 2, Ont.*

H. L. Scott (on transfer from Junior Member)

D. E. Waters (on transfer from Junior Member)

Junior Member

W. B. Large (on transfer from Student)

C. W. Naigle (on transfer from Student)

J. M. Robertson (on transfer from Student)

C. H. Siebs (on transfer from Student)

W. N. Sinclair (on transfer from Student)

Student

M. Lloyd, Dalhousie University, Halifax, N.S.: *103 Russell St., Dartmouth, N.S.*

BOOKS

Dictionary of Aeronautical Engineering. By J. L. Nayler. George Newnes Ltd., London, 1959. 318 pages. Illus. £1-10-0.

This dictionary provides concise definitions of the many terms currently used in the various fields of aeronautical engineering. They are arranged in precise alphabetical order and cover as wide a field as possible in a book of this size. In a great number of cases, these definitions are clarified by illustrations to provide the reader with a complete understanding of the descriptions or concepts. Mathematical expressions are provided where necessary; however, these are kept to a minimum.

Special emphasis has been placed on the following: Aerodynamics, Aero-Engines, Artificial Satellites, Electronics, Guided Missiles, Helicopter Engineering, High Speed Flight, Jet Propulsion, Propellants, Rockets and VTOL Aircraft.

Although rather small, it is quite complete and is of value to both the student and expert alike. One of its good points is its over-all size, 8" × 5", which makes it very convenient as a ready reference and, when one compares the cost of this dictionary with much larger ones now on the market, it is considered good value for the money.

W. A. Chisholm

Advances in Aeronautical Sciences. Editorial Committee T. von Kármán, A. M. Ballantyne, R. R. Dexter, H. Blenk, M. Roy and H. L. Dryden. Pergamon Press, London, 1959. Two volumes, 1,144 pages. Illus. $30.00.

These two volumes represent the Proceedings of the First International Congress in the Aeronautical Sciences, held in Madrid in September 1958. As an assembly of information on the state of the art as it existed in 1958, this collection of papers by the leading authorities from 12 countries can have few equals. It covers such diversity of subjects as Inertial Guidance, Noise, VTOL/STOL, Magnetohydrodynamics, Human Disorientation and Heat Resistant Materials and extends well into the realms of Hypersonics and Space Flight. It is pleasing to note that the paper by Dr. A. A. Dorodnicyn of the USSR is included; this paper did not appear in the original programme but was presented at the Congress as an unexpected and very welcome "extra".

It is all too common in works of this sort to omit all reference to the discussions following each paper. It is therefore particularly gratifying to find that in this instance some of the discussion has been included; greatly enhancing the value of the papers concerned. But this has not been done consistently. The papers were presented, and the discussion conducted, with simultaneous translation and, presumably, with tape-recording. It should have been a relatively easy matter to record and publish all the discussion of all the papers. It is a pity that this was not done.

Of the forty-six papers, thirty-five are in English, seven in French, three in German and one in Spanish. (Dr. Dorodnicyn gave his paper in English.) Considering the wide variety of sources and authors, a surprisingly uniform presentation has been achieved and the figures are excellent. A useful feature is the index, arranged in two parts as an Author Index and a Subject Index, which appears at the end of Volume 2. The pages are numbered consecutively through the two volumes and there is no index in Volume 1. (The Foreword by Dr. von Kármán, however, appears at the beginning of both volumes, a duplication which seems rather unnecessary.)

The Second Congress will be held in Zurich this year and no doubt the series will be continued thereafter. The accumulated Proceedings of these meetings will prove a noteworthy addition to aeronautical literature and these first volumes have established a high standard.

H. C. Luttman

Space Technology. Edited by Howard S. Seifert. John Wiley & Sons, Inc., New York, 1959. 1109 pages. Illus. $22.50.

Because of the concentration of industrial organizations active in astronautics on the West Coast and the recent enhanced general and industrial interest in the subject, the University of California organized a course on space technology. The course was attended by several thousand students and was seen by means of kinescope film by nearly a hundred thousand persons elsewhere in the USA and Canada. It was designed to be a genuine technical help to the graduate engineer rather than being aimed at the popular lecture level. The most capable men available in the country were engaged to give lectures and the subjects were organized to cover nearly every aspect of space flight. This book contains expanded versions of almost all the lectures of the series.

The book comprises five parts after the introductory two chapters on what space technology is and why it is of concern to us. Space technology refers to all the interacting fields of science and engineering that must be used in achieving transportation and exploration beyond the terrestrial atmosphere. The five main parts are: Flight Dynamics, Propulsion and Structures, Communications, Guidance and Control, Man in Space and Present and Future Applications of Space Technology.

The eleven chapters on Flight Dynamics include the equations of motion and trajectories, perturbation theory, the Vanguard satellites, lunar flight trajectories, interplanetary operation, low-thrust flights, time dilatation effects in space travel, heat transfer and the possibility of a safe landing. The seven chapters on Propulsion and Structures cover rocket fundamentals (chemical, liquid, solid and nuclear), magneto-hydrodynamics, structural materials and analyses, and integrated design analysis. Part 4 on Communications, Guidance and Control has six chapters covering communication problems and capability, radio guidance and mid-course and terminal guidance. Man in Space is the theme of four chapters dealing with space environment, medical aspects, cabin and personal equipment, and crew performance. The final part on Present and Future Applications of Space Technology deals with IGY research in the upper atmosphere, scientific uses of space vehicles and a panel discussion on "What the Future Holds".

The treatment is thorough and detailed; theory and equations are developed to the practical useable stage and examples are given. There is an abundance of illustrative and reference material as the figures total 538 in number and there are 594 bibliographic references. This book is close to being a designer's handbook but at the same time it is generally quite readable if some mathematical developments are skimmed over.

System design and optimization analyses are emphasized in several sections of the book because this approach is essential to the success of a space vehicle. The design for the optimum value by compromise and close fitting of hardware to function is discussed; for

distribution of weight among the several stages of a composite vehicle; for propulsion characteristics; for shape of trajectory; for satellite life time considering the purpose of the vehicle; and for choice of paths and propulsion systems for interplanetary missions. An exhaustive study is made of structural design analysis and optimization. A statement of the structural problem may involve more than 70 equations and over 100 variables and parameters for each stage of a vehicle.

Seifert says: "It is a significant sign of the times that men of sound training and proven ability are willing to accept an invitation to speculate in print on such subjects as lunar landings and Mars probes. Space technology is indeed now an established and important part of our culture". In the panel discussion that ends the text of the book Richard W. Porter says "What does the future hold? Problems, hard expensive work, risk, perhaps physical danger for some, yet opportunity for brilliant engineering achievements, many material benefits for mankind, and ultimately knowledge and understanding beyond our wildest imagination".

This book is recommended as a general reference work, a guide to significant publications on space technology and as a unique engineering vade mecum for engineers concerned with the subject.

DR. D. A. MACLULICH

Introduction to the Mechanics of the Solar System. By RUDOLF KURTH. Pergamon Press, New York, 1959, 177 pages. Illus. $6.50.

This little book is based on a lecture course given by the author in the University of Manchester. Like the author's "Introduction to the Mechanics of Stellar Systems" of 1957, it was originally written in German. Dr. A. H. Batten has translated the book being reviewed, and in my opinion he did a good job. It certainly reads as if written in English.

The book is meant primarily for students, with an emphasis on fundamental principles and methods, and not on long and complicated formulae. In stating his aims in the Preface the author gives as his first: "Nearness to natural reality – as is seen, for example, in the occasional use of such names as Jupiter and Saturn" – highly commendable to be sure, for a book with such a title.

Some knowledge of analysis, analytical geometry and linear algebra is assumed. Vector methods are used throughout.

In the first chapter, Kepler's own method is used to show how the three laws bearing his name were discovered from observations. The second chapter deals with the dynamics of a single planet. From Newton's laws of gravitation and motion, generalized forms of Kepler's laws are deduced. The methods of Laplace and of Gauss for determining the approximate orbital elements of a planet or comet from three observations are presented.

The influence of the planets on each other is covered in the third chapter. For solutions of the perturbation equations partly analytical and partly numerical procedures are used. The special case of the three-body problem where the mass of one is negligible and the relative motion of the other two is nearly circular, the so-called "problème restreint" is examined in some detail. The last chapter is titled "The Planets and the Moon as Rigid Bodies". Approximate formulae for precession and nutation are derived. Small discrepancies which remain between observation and exact theory are probably due to the elasticity of the earth. Tides and the shape of celestial bodies are not considered.

Although this book does not attempt to cover as much ground as the classical "An Introduction to Celestial Mechanics" by F. R. Moulton, nevertheless it does do well for the serious student exactly what the title implies.

W. F. CAMPBELL

Aircraft and Missile Design and Maintenance Handbook. By C. A. OVERBEY. The Macmillan Company, New York, 1960. 369 pages. Illus. $9.75.

According to the author's preface, this book is aimed at "engineers, inspectors, technicians and mechanics who work with aircraft and missiles". His intent is "to save time for the user by providing, in a single source, data which have been scattered throughout the military and industrial literature" and also to provide "on the basis of his own experience, and that of his associates, instruction in the proper use of tools and materials".

This is a relatively modest aim, and the author has laid no claim to any significant originality of thought. In fact, the tabulated material which makes up a large part of the book is almost entirely selections of the more commonly used AN and MS standards, extracts from ANC-5, CAM-18 and similar reference sources, hardware manufacturers' catalogues and data sheets, and standard engineering handbook data, including all the familiar conversion tables. The selection of these is a little uneven: some, such as escape velocities from the planets or specific impulse of propellant combinations, seem a little exotic for the obviously-intended user of the book; others, such as formulae for areas of simple plane figures, nomenclature for parts of a circle and solution of right-angled triangles, are unnecessarily elementary.

The textual material, which is generally well illustrated, consists largely of descriptions of shop processes, materials, installation practices and standard repair methods. Again, these are largely extracted from familiar reference sources and constitute little more than a collection of standard aircraft manufacturing practices.

The book is, in general, slanted toward the needs of the senior inspector or mechanic in the smaller activity which has not adopted its own selection of hardware and process standards. It may also be useful for the field service or shop liaison engineer who must advise on installations or repair schemes without access to the normal reference sources which most engineers are accustomed to using. Most larger companies would probably prefer their technical staff to use their own published selections of such standards.

H. H. WHITEMAN

Advances in Semi-Conductor Science. Edited by H. BROOKS, Pergamon Press, New York, 1959. 533 pages. Illus. $15.00.

The Proceedings of the 1958 International Conference on semi-conductors comprise one hundred and thirty-seven carefully selected papers. In addition, the discussions that follow the papers represent a valuable part of the proceedings, in particular the summary session sets the subjects presented at the Conference in their proper perspective. The papers have been logically organized in twenty sessions including the summary session. These sessions may be broadly grouped under the following general headings: stationary states of semi-conductors; fundamental transition processes; recombination, trapping and optical phenomena; surfaces; and finally, transport. In the following paragraphs, some of the topics discussed under these headings will be reviewed.

Under stationary states of semi-conductors, the approximations of the band theory are classified and the validity of these approximations is examined for various semi-conductors. The related papers show how, in the last few years, emphasis has shifted from a priori band calculations to a semi-empirical approach in which cyclotron resonance data is used to determine some of the parameters involved in the theory. The chemical viewpoint is presented and shown to be a useful guide in the discovery of new semi-conducting ma-

terials despite the problem of relating the qualitative considerations of the band picture to the more quantitative details of the band picture; the interesting results obtained with new semiconductors such as A3 Sb (where A is an alkali metal), Au Cs and the III – VI compounds are described. A rather complete description is given of semi-conductor band structures according to the following classifications:

(a) In the first class are those materials for which good cyclotron resonance and magneto-optical data are available;

(b) In the second class are those materials for which the knowledge of band structure depends mainly on the interpretation of transport properties supplemented by optical measurements of the band gap.

The papers which have been grouped under the heading of fundamental transition processes present convincing evidence of the existence of excitons both in the elemental and in the compound semi-conductors. One paper summarizes the theory of band-to-band transitions of the direct type or of the indirect type involving the emission or absorption of phonons, with the new refinement of including the effect of Coulomb interaction between electron and hole on the shape of the absorption vs frequency curve in the continuum range. Results are given of solid state spectroscopic research complemented by the application of a magnetic field; in the field of spectroscopy of semi-conductors, a useful method is described to determine the effective mass of charge carrier from dispersion and rotation data. Progress is reported on the theory of band-to-band Auger recombination and in the work on nuclear and spin resonance in centres.

The papers on recombination, discuss:

(a) Auger recombination;

(b) Radioactive recombination involving no crystal defects, and

(c) Recombination, both radiative and non-radiative, at defects, such as chemical impurities or dislocations.

Hole-trapping is shown to drastically reduce the recombination rate in silver halides that have been grown in air, and an approach is given to overcoming the difficulties usually presented by traps.

The papers on surfaces cover four main categories:

(a) Real surfaces of germanium and silicon;

(b) The "clean" or "imaginary" surfaces;

(c) The transport properties of electrons and holes in surface layers, and

(d) The chemistry of adsorption and structure of surfaces.

On the subject of transport in semiconductors, about three-quarters of the papers are based on the generally accepted theme of entities in motion, pushed by an external agency and trying to return to equilibrium by scattering processes. However, the reader is shown how some interesting phenomena in semi-conductors cannot be understood in terms of the general theme and the need for new concepts is established. One of these concepts is the application of modern quantum-mechanical methods to gain a conception of the transport process better than that provided by the usual Boltzmann equation. Another is the concept of hopping charges which are introduced to understand low-mobility semi-conductors.

In conclusion, the book provides an essentially up-to-date summary of the research work in existence at the time of the conference. Thus, it would be of particular assistance to interested readers who have not been able to remain current with the subject of semiconductors because of the rapid expansion of research in this field, and the massive documentation published every year on the subject.

F/L B. P. Charbonneau

Surface Effects on Spacecraft Materials. Edited by F. L. Clauss. John Wiley & Sons, 1960. 404 pages. Illus. $11.50.

The first symposium on surface effects on spacecraft materials was held in Palo Alto, California, on May 12-13, 1959. These transactions comprise twenty papers and discussions by scientists who are seriously concerned with the subject matter.

The subject matter runs from concepts of the radiation balance of orbiting bodies to materials and the gaseous-solid interface effects on material properties. The space environment cannot be described by a unique set of conditions. High altitudes and outer space provide a gradation of new features, the intensification of old ones and a mixed blessing from the degeneration of the ground level atmosphere. Present research is in a transient state of developing new concepts, new experimental techniques and the reassessment of fundamental chemical and physical material properties. A single symposium of twenty papers cannot be expected to isolate all the problems let alone dispatch them. For a symposium of twenty papers however, the one at Palo Alto provides an excellent outline of some of the many fascinating problems which are being explored in the hectic lanes of space and in the quiet atmosphere of back rooms.

Very briefly, there is the prediction of satellite temperatures and the estimation of uncertainties and their origins; the application of passive temperature control to the Explorers and Pioneers III and IV and the results of in-flight measurements; the techniques of producing organic and ceramic coatings and the measurement of thermal emittances; theory, techniques and instruments for the measurement of reflectance and emissivity including experimental results; surface effects in high vacuum; volatility of organic coatings; the effect of high vacuum on mechanical properties with an experimental investigation of the strength reversal due to gaseous atmosphere effects and temperature; the mechanism of friction; high vacuum chambers; ultraviolet solar radiation, associated photoelectric emissions and the degradation of polymeric films; the estimation of sputtering yields and erosion by interplanetary dust.

Of particular interest and value to those engaged in research.

A. H. Hall

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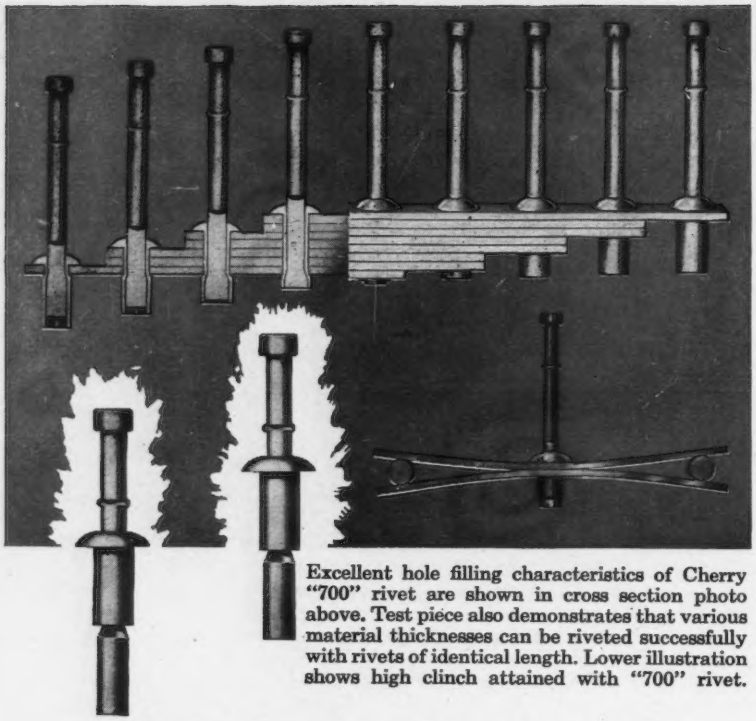

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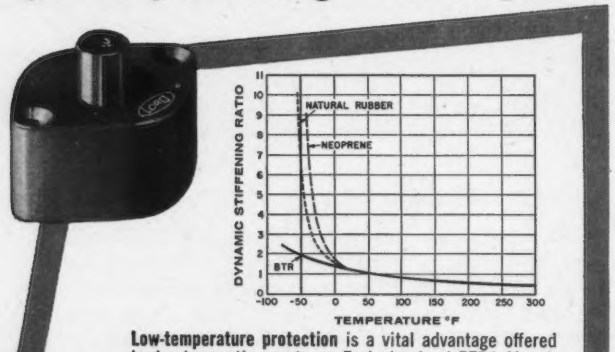

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